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JAN 78 S T MAYNORD, B LOFTIS, D G FONTANE

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TECHNICAL REPORT H-78-1

TEMPERATURE ANALYSIS AND SELECTIVE-WITHDRAWAL DESIGN STUDY TALLAHALA CREEK LAKE, MISSISSIPPI

Mathematical Model Investigation

by

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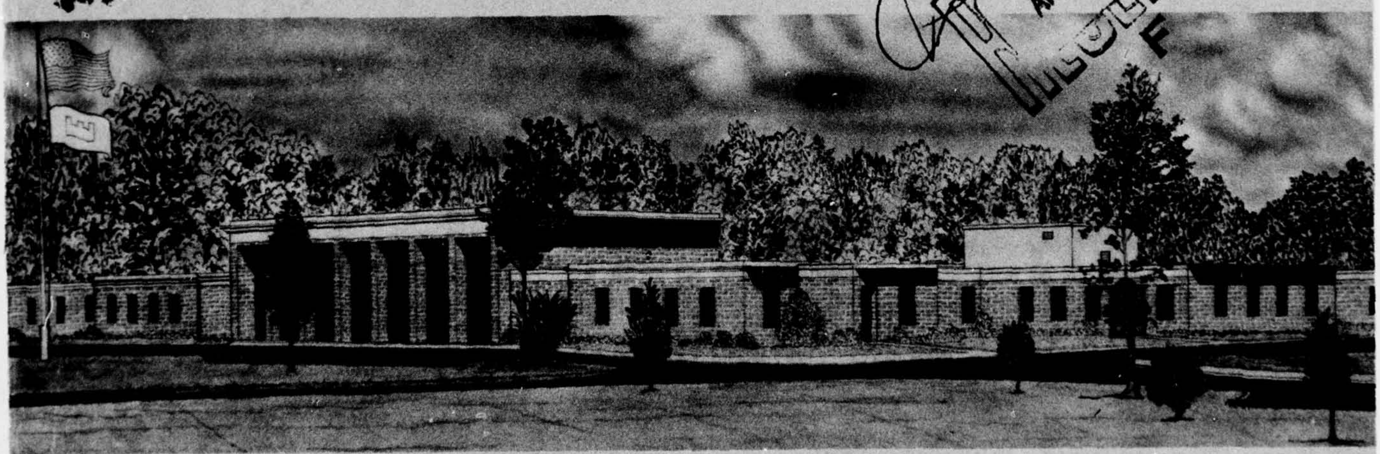

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A numerical simulation model was used to evaluate the thermal characteristics of the proposed Tallahala Creek Lake near Laurel, Mississippi. Several multilevel intake configurations were evaluated on the basis of capability of meeting a natural stream temperature objective. Each of the multilevel configurations exhibited similar performance in meeting the temperature objectives. One of the configurations was recommended because it will provide simpler operation. 2> next page

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20. ABSTRACT (Continued).

Additionally, a cursory analysis of anticipated dissolved oxygen content in and downstream of the lake was performed. Based on simulated oxygen profiles in the lake and potential reaeration through the Tallahala Creek Lake outlet works, it is expected that acceptable levels of dissolved oxygen will exist immediately downstream of the structure.

PREFACE

The mathematical model investigation of Tallahala Creek Lake reported herein was authorized by the Office, Chief of Engineers, U. S. Army, on 19 August 1974 at the request of the U. S. Army Engineer District, Mobile (SAM). An earlier investigation of Tallahala Creek Lake was completed in June 1973 and a letter report was forwarded to SAM. The model study reported herein reflects various structural and operational changes in Tallahala Creek Lake not investigated in the earlier study.

The investigation was conducted during the period April-November 1975 in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES), under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and Mr. J. L. Grace, Jr., Chief of Structures Division, and under the supervision of Mr. J. P. Bohan, Chief of the Spillways and Channels Branch. The study was conducted by Messrs. S. T. Maynord and B. Loftis. This report was prepared by Messrs. Maynord, Loftis, and D. G. Fontane.

Directors of WES during this study and the preparation and publication of this report were COL G. H. Hilt, CE, and COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
square feet	0.09290304	square metres
square miles (U. S. statute)	2.589988	square kilometres
acres	4046.856	square metres
acre-feet	1233.482	cubic metres
cubic feet per second	0.02831685	cubic metres per second
Btu (International Table)	1055.056	joules
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

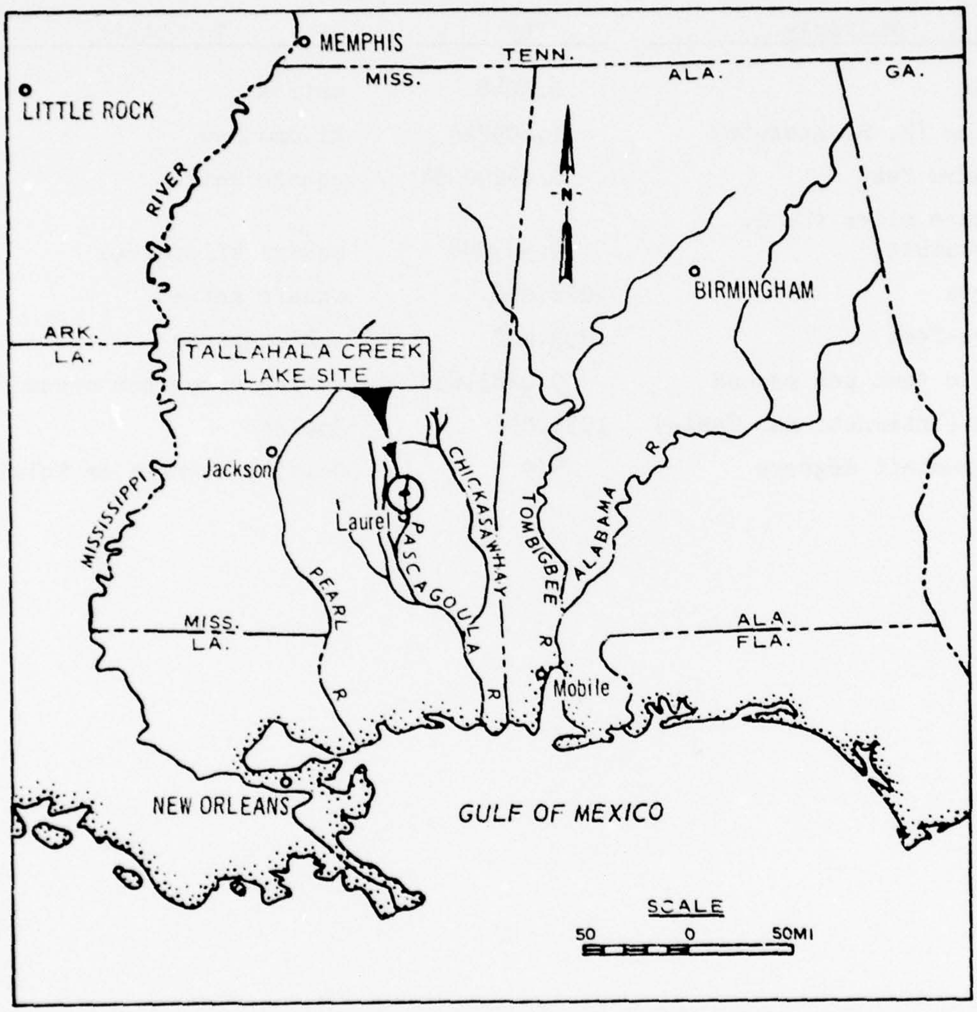

Figure 1. Vicinity map

TEMPERATURE ANALYSIS AND SELECTIVE-WITHDRAWAL DESIGN STUDY
TALLAHALA CREEK LAKE, MISSISSIPPI

Mathematical Model Investigation

PART I: INTRODUCTION

Purpose

1. The purpose of this study was to investigate the temperature structure to be expected within the proposed Tallahala Creek Lake and to determine a selective-withdrawal intake configuration that will allow operation to satisfy downstream water-quality objectives.

Project Description

2. The Tallahala Dam will be located on the Tallahala Creek approximately 13 miles* north of Laurel, Mississippi, and will have a drainage area of 152 square miles (Figure 1). An 8,000-ft-long earth-fill dam will impound water for water supply, water-quality management, and flood control. The lake formed by the dam will be approximately 8 miles long and will provide 128,360 acre-ft of storage at el 317.5,** which will be the top of the flood control pool. The storage allocation will include 67,300 acre-ft for flood control, 36,800 acre-ft for water supply, and 12,400 acre-ft for water-quality control. The top of the conservation pool will be at el 306.5 and the bottom of the reservoir will be at el 270.0. The surface area of the lake at the top of the conservation pool will be 4,845 acres. Releases from the lake will be made through an outlet works with a 10-ft-diam conduit in the dam and over a 300-ft-long emergency spillway.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

** All elevations (el) cited herein are in feet referred to mean sea level.

3. The outlet works will consist of an intake structure with provisions for making selective-withdrawal and flood releases. The selective-withdrawal releases will pass through two 10- by 4.75-ft wet wells, each of which will have two 3.0- by 4.0-ft intakes, one at el 289.0 and one at el 298.0, with hydraulically operated sluice gates. The two intakes at el 298.0 will discharge into the sides of the wet wells, and the two at el 289.0 will discharge into the front faces. The flows from each of the wet wells will be controlled by 2.0- by 2.5-ft sluice gates at el 272.0. The flows from the wet wells will discharge into the flood control conduit just downstream of the service gates. Each wet well will pass 85 cfs, and the combined capacity for both wet wells will be 170 cfs.

Approach

4. The study was accomplished with the use of a numerical simulation model. The approach involved the selection of several study years and simulation of lake operation for each of these years. Study years selected had combinations of streamflow quantities and air temperatures that could create extreme conditions of thermal stratification. The data required for the simulations were lake inflows and outflows, inflow stream temperatures, meteorological data for each of the study years, geometry of the lake, and geometry of the intake structure.

5. The heat transfer into and out of the lake was evaluated and the heat was distributed within the lake. A heat budget was maintained throughout the simulation period. An objective temperature was specified for each simulation day, and an operating scheme was determined. The operation scheme for any day was the combination of open ports that minimized the difference between the objective downstream temperature and the predicted release temperature. The output from the simulation included a comparison between objective and release temperature in graphical form throughout the simulation period as well as tabular summaries for each day and plotted profiles of temperature within the lake at specified times of the year. The numerical simulation model was also

used to simulate the dissolved oxygen (D.O.) structure of Tallahala Creek Lake. The purpose of these simulations was to evaluate the effects of reservoir operation upon the D.O. regime of the lake. A description of the simulations and the results of the simulations are presented in Appendix A of this report.

PART II: MODEL DESCRIPTION

6. The downstream release characteristics and the internal temperature and D.O. structure for Tallahala Creek Lake were predicted using a numerical simulation model. The model (WESTEX) used in conjunction with this investigation was developed at the U. S. Army Engineer Waterways Experiment Station (WES) based on the results of Clay and Fruh,[1] Edinger and Geyer,[2] Dake and Harleman,[3] and Bohan and Grace.[4] The D.O. portion of the WESTEX model is described in Appendix A.

7. The WESTEX model provides a procedure for examining the balance of thermal energy imposed on an impoundment. This energy balance and lake hydrodynamic phenomena are used to map vertical profiles of temperature in the time domain. The model includes computational methods for simulating heat transfer at the air-water interface, heat advection due to inflow and outflow, and the internal dispersion of thermal energy. The model is conceptually based on the division of the impoundment into discrete horizontal layers. Fundamental assumptions include the following:

- a. Isotherms are parallel to the water surface both laterally and longitudinally.
- b. The water in each discrete layer is isotropic and physically homogeneous.
- c. Internal advection (between layers in the lake) and heat transfer occur only in the vertical direction.
- d. External advection (inflow into and outflow from the lake) occurs as a uniform horizontal distribution within each layer.
- e. Internal dispersion of thermal energy is accomplished by a diffusion mechanism which combines the effects of molecular diffusion, turbulent diffusion, and thermal convection.

8. The surface heat exchange, internal mixing, inflow, and outflow processes are simulated separately and their effects are introduced sequentially at daily intervals.

9. The WESTEX model employs an approach to the evaluation of surface heat transfer that was developed by Edinger and Geyer.[2] This method formulates equilibrium temperatures and coefficients of surface

heat exchange. Equilibrium temperature is defined as that temperature at which the net rate of heat exchange between the water surface and the atmosphere is zero. The coefficient of surface heat exchange is the rate at which the heat transfer process will occur. The equation describing this relation is

$$H = K(E - \theta) \tag{1}$$

where

H = net rate of surface heat transfer, Btu/ft^2/day*

K = coefficient of surface heat exchange, Btu/ft^2/day°F

E = equilibrium temperature, °F

θ = surface temperature, °F

The computation of equilibrium temperature and heat exchange coefficient is based solely on meteorological data as outlined by Edinger, Duttweiler, and Geyer.[5]

10. The net heat exchange at the surface is composed of seven heat exchange processes. These are the following:

- a. Shortwave solar radiation.
- b. Reflected shortwave radiation.
- c. Long-wave atmospheric radiation.
- d. Reflected long-wave radiation.
- e. Heat transfer due to conduction.
- f. Back radiation from the water surface.
- g. Heat loss due to evaporation.

For every day of meteorological data, the seven heat exchange terms can be evaluated and the net heat exchange expressed in terms of an equilibrium temperature and an exchange coefficient.

11. All of the surface heat exchange processes, with the exception of shortwave radiation, affect only approximately the top few feet of the lake. Shortwave radiation penetrates the water surface and increases the temperature at greater depths. Based on laboratory investigations, Dake and Harleman[3] have suggested an exponential decay with

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* For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix C).

depth for describing the heat flux due to shortwave penetration.

12. The surface heat exchange concepts are implemented in the WESTEX model by the exponential penetration of a percentage of the incoming shortwave radiation and the placement of the effect of all other sources of surface heat exchange into the surface layer. This can be expressed mathematically by the following two equations

$$H_s = K(E - \theta) - (1 - \beta)S \tag{2}$$

$$H_i = (1 - \beta)Se^{-\lambda z_i} \tag{3}$$

where

H_s = rate of heat transfer into or out of surface layer, Btu/ft^2/day

β = percentage of incoming shortwave radiation absorbed in the surface layer

S = rate of total incoming shortwave radiation, Btu/ft^2/day

H_i = rate of heat absorbed in layer (i), Btu/ft^2/day

e = natural logarithmic base (2.7183)

λ = absorption coefficient, ft^{-1}

z_i = depth below surface, ft

13. The process of inflow into a lake is simulated in WESTEX by the placement of inflow quantity and quality at that layer where the density of the lake corresponds most nearly to the density of the inflow. Research efforts and physical model studies at WES have indicated that entrainment-induced density currents can exist and flow upstream along the surface into the turbulent mixing zone caused by the inflow. Entrainment is implemented in the model by augmenting the inflow quantity with a volume from the surface layer. Characteristics of inflow and entrained flow are averaged, and mixed values of density, temperature, and other water-quality parameters are determined. The mixed density is used to determine placement of the total quantity and mixed quality. Simulation of the process of inflow displaces upward a volume equal to the total inflow quantity. This upward displacement is reflected in the

model by an increase in the water surface. A corresponding decrease in water surface occurs as a result of the outflow process.

14. The internal dispersion process is represented by an internal mixing scheme based on a simple diffusion analogy. Internal mixing transfers heat and other water-quality constituents between adjacent layers. The magnitude of the transfer between two layers is a percentage of the total transfer required to completely mix the two layers. This percentage is a mixing coefficient that is defined for every layer. Data input includes values of the mixing coefficient at the top and at the bottom of the lake. An exponential fit between the two extreme values is used to determine the appropriate coefficient at each layer.

15. The outflow component of the model incorporates the selective-withdrawal techniques developed by Bohan and Grace.[4] Transcendental equations defining the zero velocity limits of the withdrawal zone are solved with a half-interval search method. With knowledge of the withdrawal limits, the velocity profile due to outflow can be determined. The flow from each layer is then the product of the velocity in the layer, the width of the layer, and the thickness of the layer. A flow-weighted average is applied to water-quality profiles to determine the value of the release content of each parameter for each time step.

16. The lake regulation algorithms have been developed to realistically simulate the field operation of a selective-withdrawal system. The selective-withdrawal system is assumed to be configured with an arbitrary number of selective-withdrawal intakes located in each of two wet wells with a separate floodgate. Maximum flows and minimum flows from each intake and from the floodgate must be specified. Also, the maximum flow for the selective-withdrawal system is specified. The algorithms attempt to numerically withdraw water at or near the objective temperature. Withdrawal will be from either one intake level, two adjacent intake levels, and/or the flood control intake depending upon the objective temperature, the temperature profile, the intake capacities, and the amount of flow to be released.

PART III: DEVELOPMENT AND ACQUISITION OF DATA

Selection of Study Years

17. For the selection of study years, statistical analyses of mean monthly streamflow and mean monthly dry bulb temperature were conducted for the period of record 1948-1968 (Plate 1). Study years were limited to this period due to lack of adequate meteorological data prior to 1948 and lack of streamflow records after 1968. Only records from March through October were considered in the selection of study years. Experience has shown that this is the period in which density stratification in the lake is affected by hydrology and meteorology. Emphasis was given to the characteristics of the spring months due to the particular importance of these months in fish reproductive cycles.

18. Combinations of above average, average, and below average hydrologic and meteorologic conditions were considered in the selection of study years. The five years discussed below were selected for the analysis of temperature at Tallahala Creek Lake.

a. 1954 - Below normal runoff occurred throughout the year. Air temperatures were above normal in February, April, and June through September. This condition would tend to allow stratification to form early in the year and remain well into the fall.

b. 1957 - Very low flows occurred in the beginning of the year and were accompanied by above normal air temperatures. The summer period had below normal runoff with average air temperatures; above normal runoff occurred from September through December. Stratification would tend to form early in the year and then decay early due to the high flows in the fall.

c. 1958 - The runoff was normal throughout the year, and the air temperatures were below normal from January through March and normal from April through November.

d. 1961 - Well above normal runoff occurred from February through April and in December with nearly normal flows for the remainder of the year. Air temperatures were below normal in January and from April through October. The high spring flows would inhibit the formation of stratification, and the low air temperatures during the

summer would result in lower than normal water temperatures near the surface.

e. 1964 - March, April, and December had above normal runoff. The remainder of the year had nearly normal flows. The monthly air temperatures were nearly normal with the exception of April (above normal) and February and October (below normal). The high flows in March and April would tend to inhibit the formation of strong stratification, while conditions throughout the remainder of the year were nearly normal.

Data Requirements

Meteorology

19. Meteorological data from the Meridian, Mississippi, Weather Station were used for this study. The weather station is located 40 miles north of the damsite. The required data consist of dry bulb temperature, dew point temperature, wind speed, and cloud cover. These data were obtained from the National Climatic Center in Asheville, North Carolina. Eight observations were furnished for each day. Daily average values were computed and used to determine equilibrium temperatures, surface heat exchange coefficients, and daily average net solar radiation quantities for the period of record.

Hydrology

20. Mean daily inflow and outflow quantities are shown in Plate 2. Hydrologic routings were conducted by the U. S. Army Engineer District, Mobile (SAM), to determine these flows.

Lake geometry

21. The area-volume curve is shown in Plate 3. This curve and other data describing the location and design of the intake structure were furnished by SAM.

Stream temperature

22. Stream temperature records for the five study years were not available. Some stream temperatures were measured between February and August 1965 at Laurel, Mississippi, approximately 10 miles below the damsite. These temperatures were reported in the Pascagoula River Comprehensive Basin Study.[6] These data were used in the development of a

regression equation relating equilibrium temperature, streamflow, and observed stream temperature. The following regression model was used.

$$\theta_t = \alpha + \beta_1 Q_t + \beta_2 E_t + \beta_3 E_{t-1} + \beta_4 E_{t-2} \tag{4}$$

where

θ = mean daily stream temperature, °F

t = Julian day

Q = mean daily streamflow, cfs

E = mean daily equilibrium temperature, °F

and α , β are regression coefficients as follows:

$\alpha = 19.475$

$\beta_1 = -0.0020$

$\beta_2 = 0.13595$

$\beta_3 = 0.1234$

$\beta_4 = 0.4095$

This equation has a correlation coefficient of 0.985 and a standard error of 2.21°F. The mean daily lake inflow temperatures (Plate 4) for the five study years were predicted using this equation.

Objective temperature

23. A least-squares analysis was used to fit a harmonic curve to the predicted stream temperatures for the five study years. The curve represents the average natural stream temperature variation to be expected during a year. The following regression model was used:

$$\theta_t = A \sin (Bt + C) + D \tag{5}$$

The coefficient B is a unit conversion from days to radians. The coefficients A , C , and D were determined by solution of Equation 5 with the Newton-Raphson technique and were computed to be the following:

$A = -13.834$

$B = 1.721 \times 10^{-2}$

$C = 1.333$

$D = 65.44$

Equation 5 was used to define the downstream temperature objective.

24. The entire record of predicted downstream temperatures was scanned for the maximum stream temperature to be expected for each day of the year. These 365 maximum temperatures were then fit to the same regression model as indicated in Equation 5. A similar sine curve was determined for the minimum temperatures to be expected each day of the year over the period of record. The coefficients for these curves are as follows:

Coefficient	Maximum	Minimum
A	-11.94	-15.66
B	1.721×10^{-2}	1.721×10^{-2}
C	1.325	1.325
D	70.63	60.25

These curves of maximum and minimum predicted downstream temperatures give an indication of the variation of natural stream temperatures from the single harmonic curve that is used as an objective temperature.

Model Calibration

25. As has been discussed previously, the WESTEX model requires the determination of coefficients of surface heat exchange distribution and internal mixing. For Tallahala Creek Lake these coefficients were determined by conducting simulations with Tallahala hydrologic and meteorologic data. Coefficients were adjusted and simulation was repeated until the predicted temperature profiles corresponded in shape and range to those observed in nearby Okatibee Lake. Okatibee Lake is located just north of Meridian, Mississippi. It is similar in size, depth, and flow magnitudes to Tallahala Creek Lake. Profiles of temperature and D.O. in Okatibee Lake were obtained from SAM (Plate 5). Isotherms predicted for Tallahala Creek Lake (Plate 8) compare favorably with Okatibee data. The following coefficients were determined from the analysis:

$$\beta = 0.6$$

$$\lambda = 0.2$$

$$\alpha_1 = 0.5$$

$$\alpha_2 = 0.3$$

where

β = percentage of incoming shortwave radiation absorbed in the surface layer

λ = absorption coefficient, ft^{-1}

α_1 = mixing coefficient at surface

α_2 = mixing coefficient at bottom

Since data did not exist to accurately determine the amount of entrainment induced by Tallahala Creek Lake inflows, simulations were conducted assuming no entrainment and entrainment of a volume equal to the volume of inflow. The simulations indicated that the effect of entrainment on the predicted thermal profiles and predicted release temperatures were negligible, and no entrainment by inflow was assumed for all subsequent simulations.

26. As mentioned previously, two inlets in the proposed intake structure will discharge into the sides of the wet wells. A previous physical hydraulic model study[7] on the outlet works for New Hope Reservoir (now designated B. Everett Jordan Reservoir) conducted at WES had indicated that side inlets could have different selective-withdrawal characteristics compared with inlets on the front face of the intake structure. For the same discharge conditions, the inlets located on the upstream face of the New Hope intake structure were approximately twice as effective in withdrawing water from above the density interface as were those located on the sides. For the Tallahala intake structure it was thought that the two proposed side inlets would not have different selective-withdrawal characteristics from front facing inlets. The New Hope intake structure was recessed back into the earth-fill dam such that the fill caused shallow depths at the side inlets. Also, the local topography at New Hope caused restricted access of flow to the side inlets in the structure. The combination of these two effects was believed to be responsible for the different selective-withdrawal characteristics of the side inlets. The intake structure at Tallahala Creek

Lake extends farther into the reservoir, and site conditions are not restrictive compared with the New Hope structure. In addition, there is a significant difference in the discharges to be released through the Tallahala and New Hope structures. Discharges tested in the New Hope study ranged from 300 to 2700 cfs whereas the selective-withdrawal capacity of the Tallahala structure is 175 cfs. Therefore, for this study, the selective-withdrawal technique in the WESTEX model was assumed to apply equally to side or front facing inlets.

PART IV: SIMULATIONS

27. Four configurations were used in the analysis of the location and operation of the selective-withdrawal intakes. Three of the configurations have selective-withdrawal capabilities. The fourth configuration allows floodgate releases only.

28. The capacity of the selective-withdrawal system was established such that the system would be large enough to pass most flows. Outflow requirements larger than the selective-withdrawal capacity must be satisfied by operation of the floodgates. Plate 6 shows an outflow-exceedance curve that was determined from a statistical analysis of daily outflow requirements from April to September for all of the study years. The exceedance curve shows that for possible selective-withdrawal capacities above about 130 cfs, even a large increase in capacity will not significantly increase the percentage of flows which can be controlled selectively. For Tallahala simulations, the selective-withdrawal system capacity was established by SAM to be 170 cfs. This capacity allows selective control of 85 percent of the flows for the study years. Thus, operation of the floodgate is required for 15 percent of the release flows from April to September for the study years.

29. The selective-withdrawal system was simulated as being configured with two wet wells each containing two intakes. While it is hydraulically possible to release flow through two intakes of the same wet well, this practice is not recommended for it may result in unequal flow distribution from the two intakes and ineffective blending as well as induce unstable hydraulic flow conditions. If blending of flows is required to meet a temperature objective, the model will use one intake location from each wet well.

30. The first intake configuration (type I) considered consisted of two wet wells and a floodgate. Each wet well contained selective-withdrawal intakes with center lines at el 298.0 and 289.0. Each intake had a capacity of 85 cfs. The flood-release conduit was a 10-ft-diam circular conduit with invert at el 272.0. Operation of this system allowed simultaneous releases from the floodgate and selective-withdrawal

intakes. Blending of floodgate releases with selective-withdrawal releases was used to achieve a downstream temperature objective during times when cold water was needed. This blending of floodgate releases might be accomplished through the use of a low-level outlet within the floodgate.

31. The second configuration (type II) considered was proposed by SAM (see paragraph 3). It consisted of two wet wells and a floodgate. Each wet well had selective-withdrawal intakes with center lines at el 298.0 and 289.0. Each intake had a capacity of 85 cfs and a minimum controllable flow of 2 cfs. The flood-release conduit was a 10-ft-diam circular conduit with invert at el 272.0. Operation of this system permitted floodgate release only when the required outflow was greater than the capacity of the selective-withdrawal system.

32. The third configuration (type III) considered consisted of two wet wells and a floodgate. One wet well contained selective-withdrawal intakes with center lines at el 298.0 and 286.0 and the other wet well contained intakes with center lines at el 304.0 and 292.0. Each intake had a capacity of 85 cfs and a minimum controllable flow of 2 cfs. The flood-release conduit was a 10-ft-diam circular conduit with invert at el 272.0. Operation of this system permitted blending of selective-withdrawal and floodgate releases. The primary advantage of type III over type II was to allow withdrawal of warm water from a higher pool elevation during the period in which warm water was required for the downstream temperature objective. Also, as with type I, more control was allowed for release of cold water due to the availability of blending floodgate releases with selective-withdrawal releases.

33. The fourth configuration (type IV) considered consisted of a floodgate only. The flood-release conduit is a 10-ft-diam circular conduit with invert at el 272.0. Operation of this system required floodgate releases for all outflows. The purpose of considering all releases to be through the floodgate was to assess the effect on downstream release temperatures if no selective-withdrawal facilities are provided. It is assumed that this approximates a worst-case operation condition

since the presence of selective-withdrawal facilities allows control for warmer releases.

34. Simulations were conducted for intake configurations types I-IV for all five study years. Plate 7 shows computed release temperatures and the required daily intake hydrographs for all simulations. The predicted structure of temperature within the lake during each of the five study years is shown in Plate 8. The isotherm plots reflect results from simulations with a type II intake configuration. Simulations with types I and III intake configurations yielded similar isotherm plots.

35. Additional simulations were conducted with a simple operation plan. The description and results of these simulations are given in Appendix B. These simulations indicated that a simple operation plan could meet temperature objectives.

PART V: DISCUSSION

36. An attempt was made in this study to satisfy an objective temperature band based on the maximum and minimum natural stream temperatures for the five study years. In general, the release temperatures fell within the objective band for intake configurations with selective-withdrawal capability (types I-III). No appreciable differences exist between the results for the five study years.

37. Results of simulations of the intake configuration without selective-withdrawal capability (type IV) yielded computed release temperatures that were cooler than natural stream temperature during the spring months. This is the period during which cooler than natural stream temperatures could adversely affect fish spawning.

38. For results of the simulations with selective-withdrawal capability (types I-III), computed release temperatures from mid-August through mid-October are above the objective temperature band. Analysis of increased selective-withdrawal capacity (type II, 300 cfs) and low-level withdrawal capabilities (represented by floodgate blending in the types I and III configurations) yielded no significant improvement in the results. The failure of the project to meet the objective band in certain instances was a result of either insufficient available storage of desired temperature water or floodgate operations necessitated by very large outflows.

39. The results of the simulations show minor differences between the intake configurations containing selective-withdrawal capabilities (types I-III). It appears that the type II configuration would be advantageous since it would be simpler to operate. It is recommended that the type II configuration be used and operated in accordance with the simple operation plan (Appendix B). It is expected that the proposed outlet works will provide sufficient reaeration to achieve acceptable levels of D.O. (5 mg/ℓ minimum) in the releases regardless of the D.O. content of the flow entering the outlet works and plan of operation (Appendix A).

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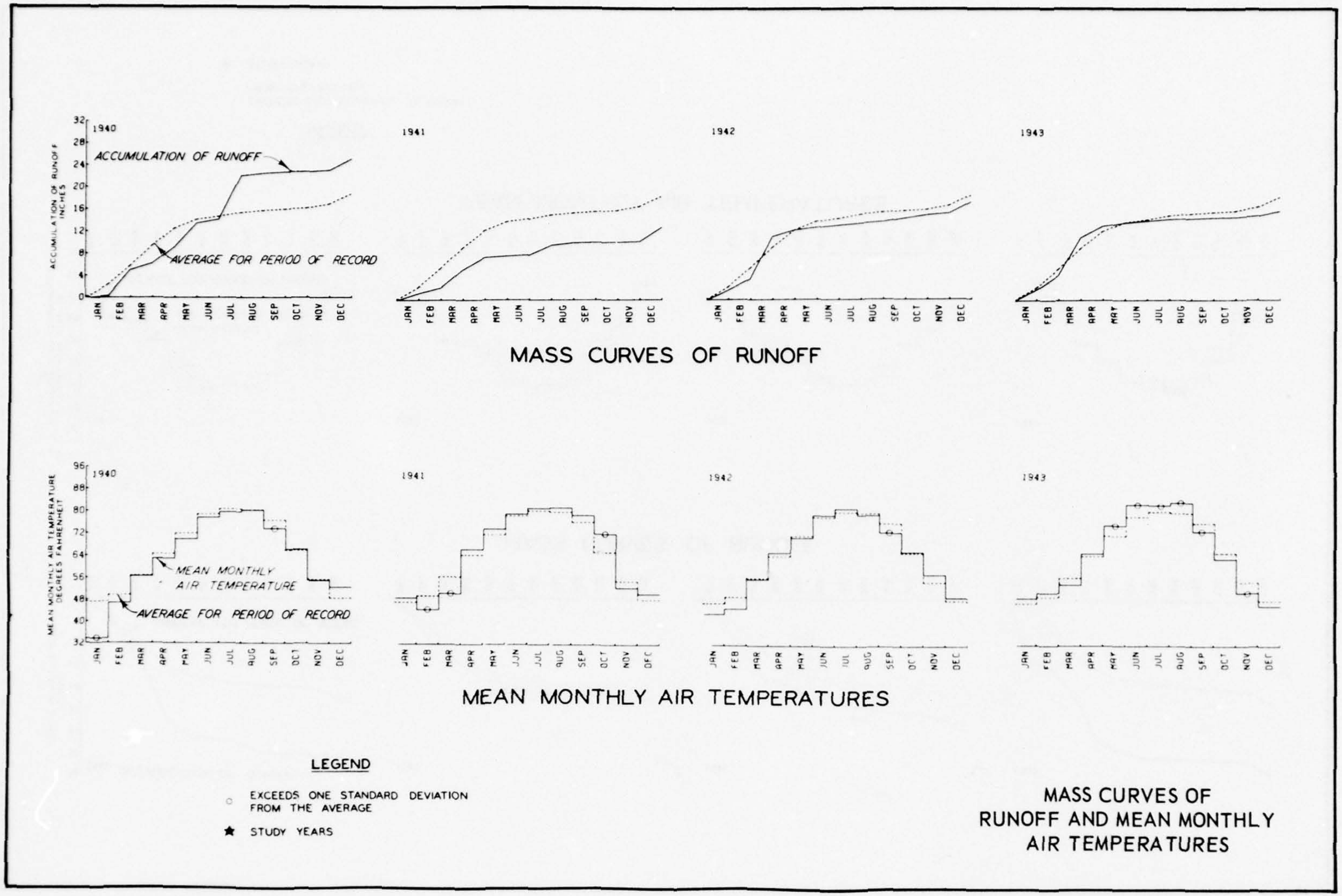

MASS CURVES OF RUNOFF AND MEAN MONTHLY AIR TEMPERATURES

PLATE 1 (SHEET 1 OF 7)

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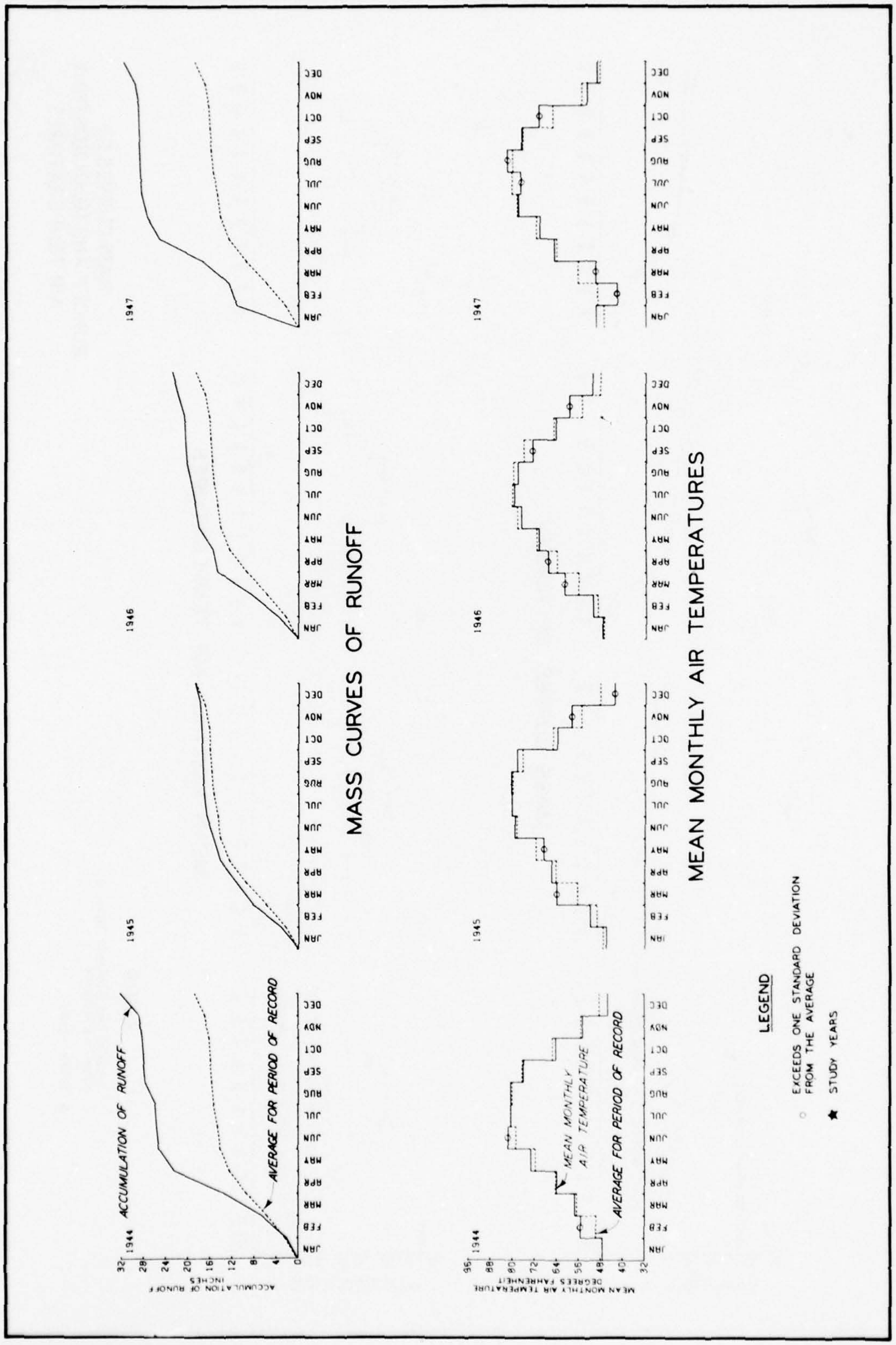

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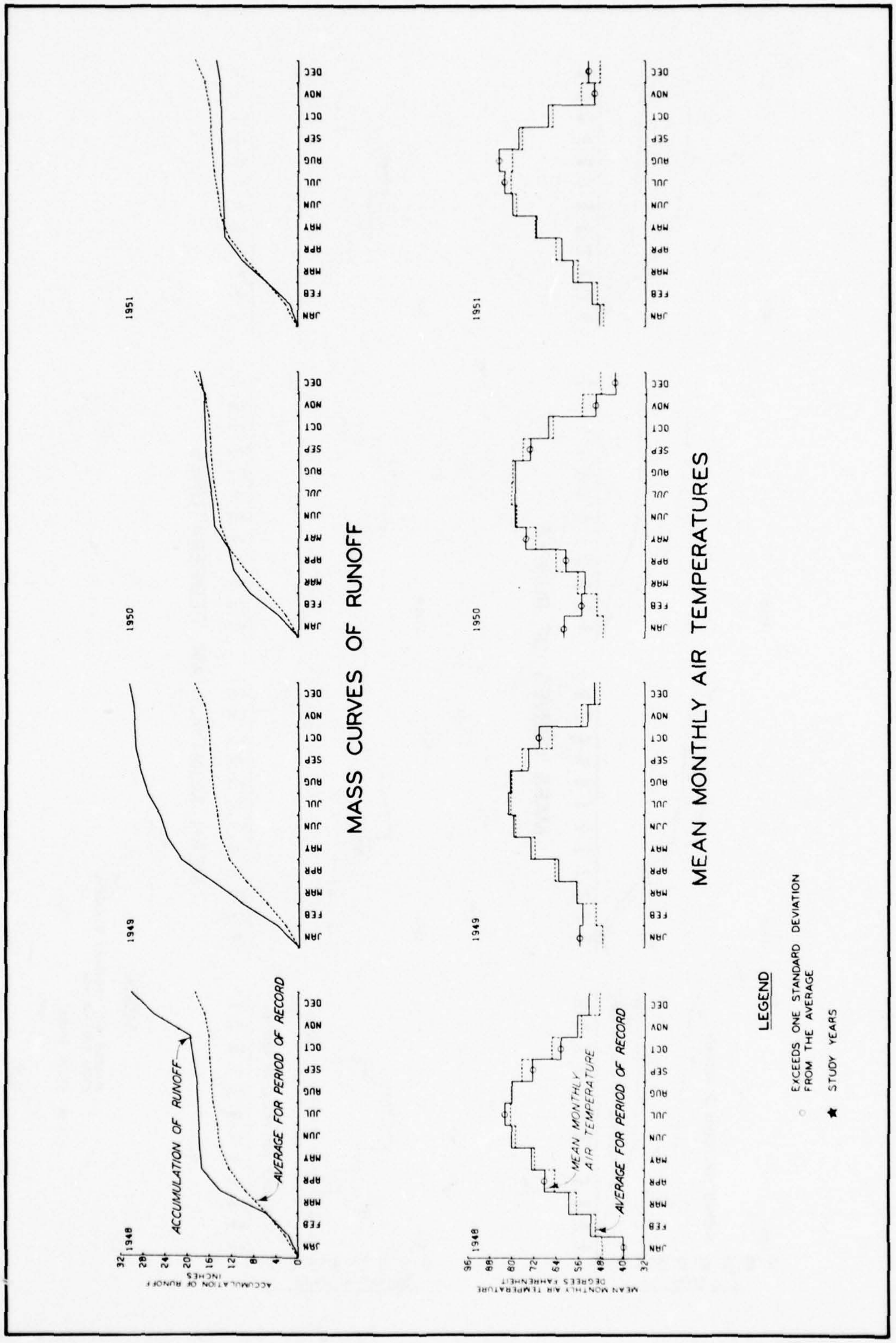

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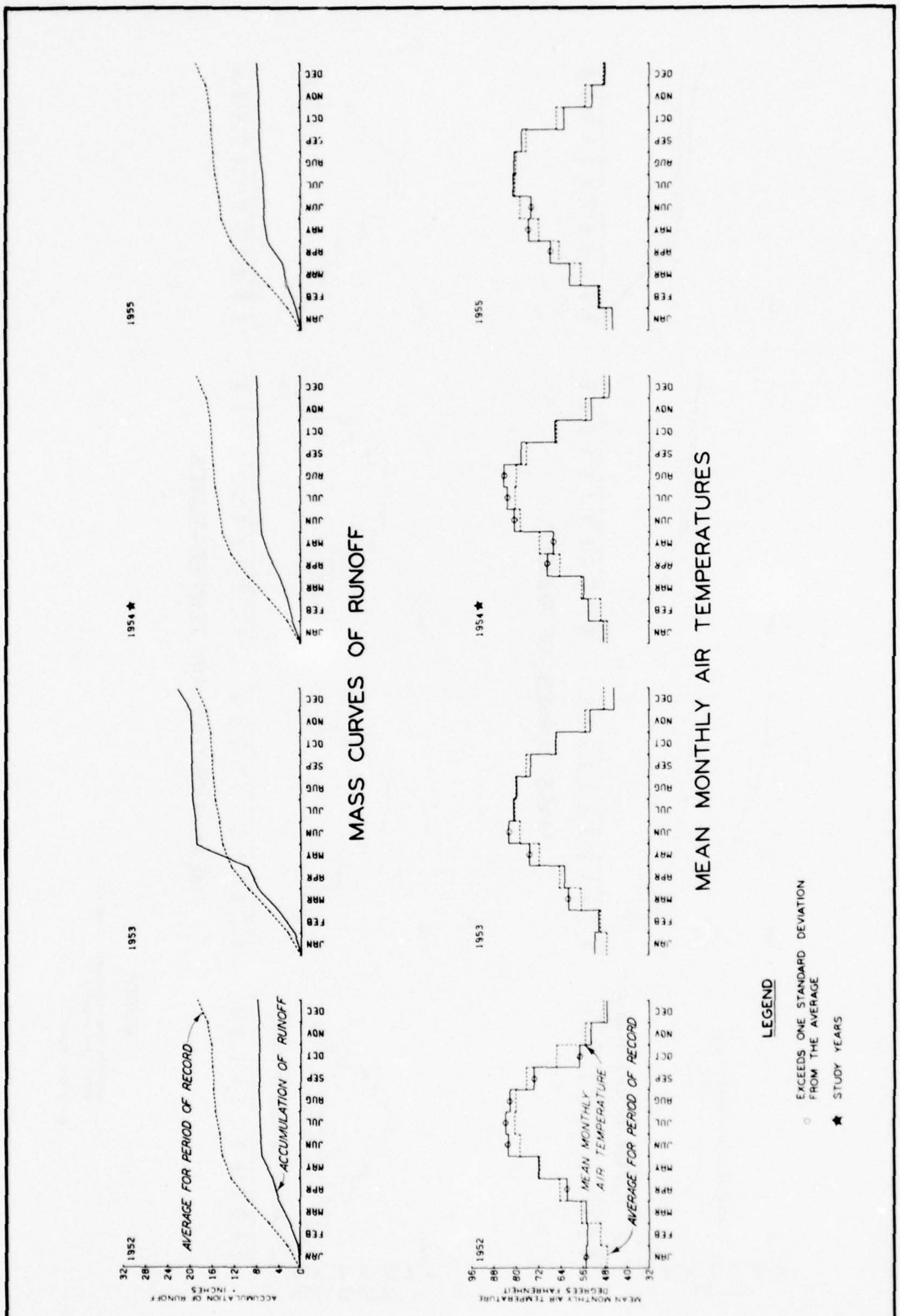

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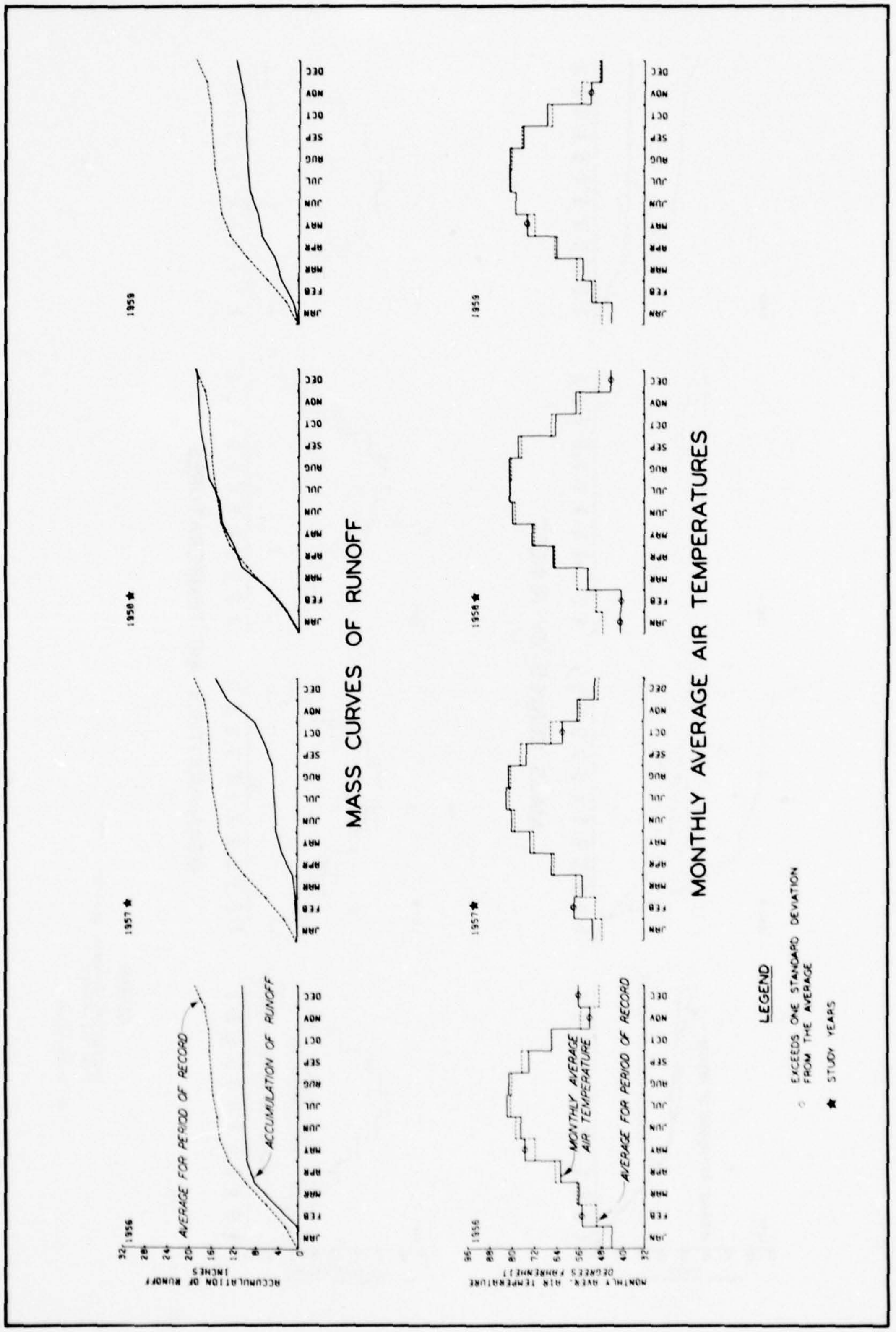
MASS CURVES OF RUNOFF
MONTHLY AVERAGE AIR TEMPERATURES
ACCUMULATION OF RUNOFF INCHES
MONTHLY AVER. AIR TEMPERATURE DEGREES FAHRENHEIT
1956
1957 ★
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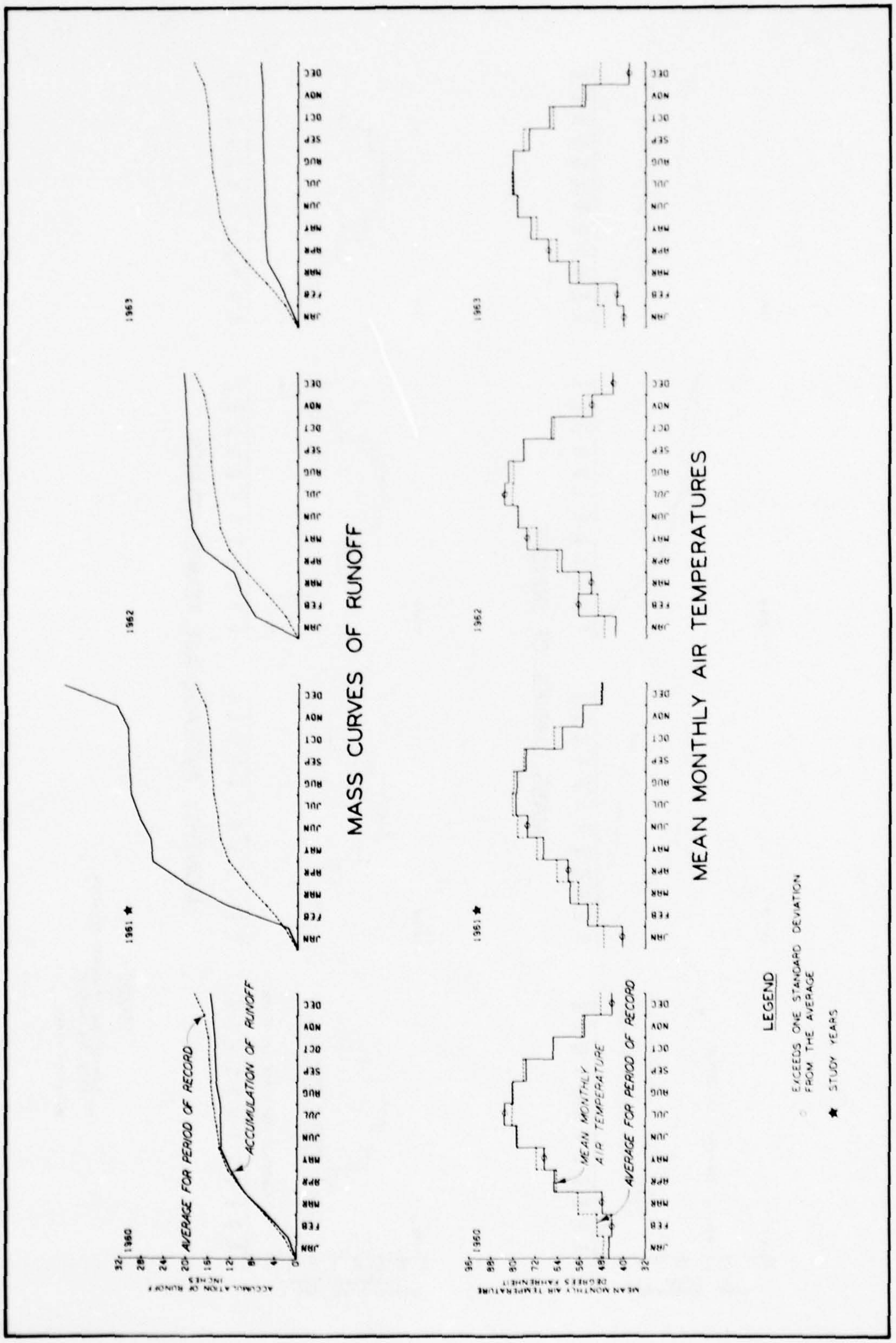
1959
AVERAGE FOR PERIOD OF RECORD
ACCUMULATION OF RUNOFF
MONTHLY AVERAGE AIR TEMPERATURE
AVERAGE FOR PERIOD OF RECORD
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LEGEND
EXCEEDS ONE STANDARD DEVIATION FROM THE AVERAGE
★ STUDY YEARS



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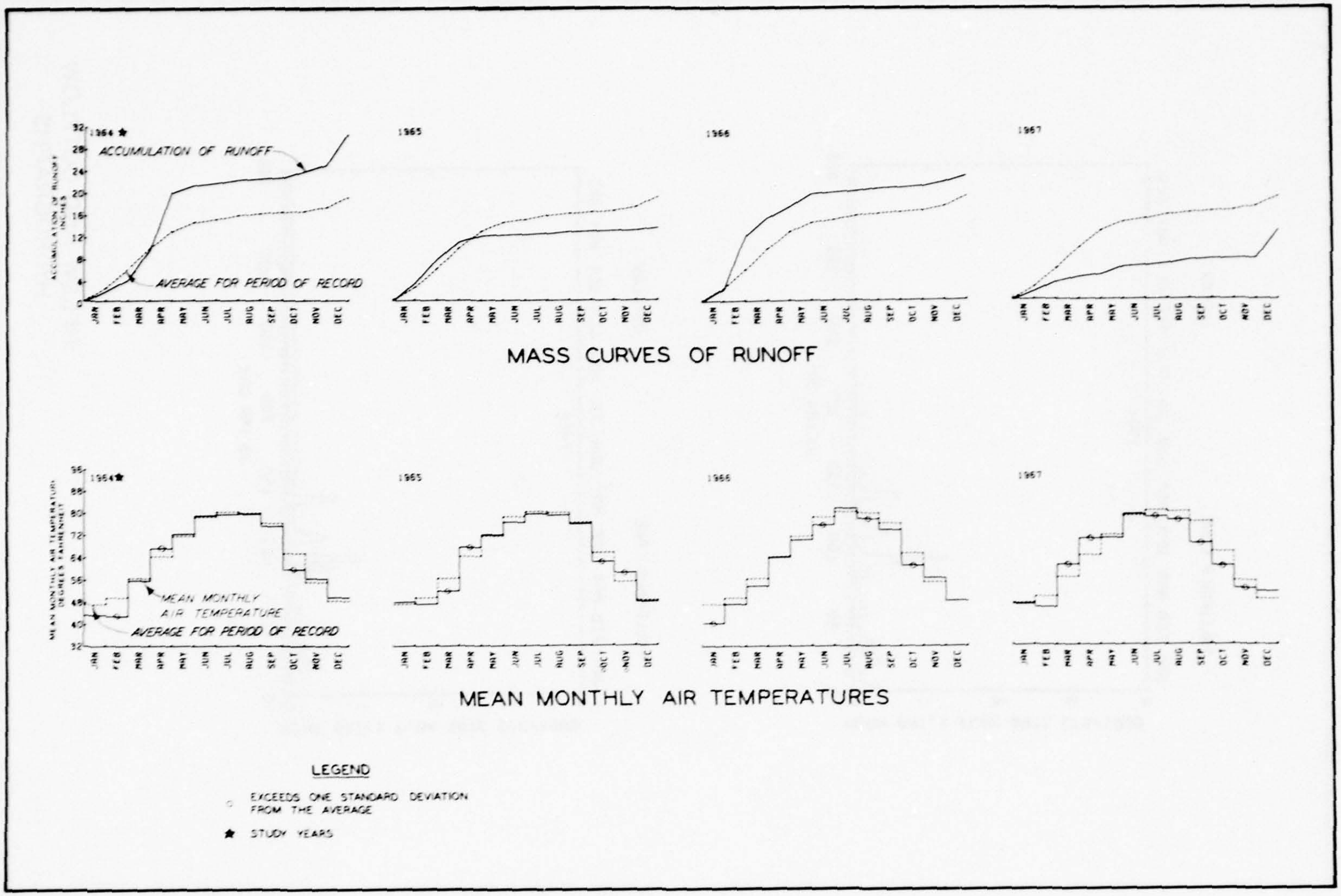

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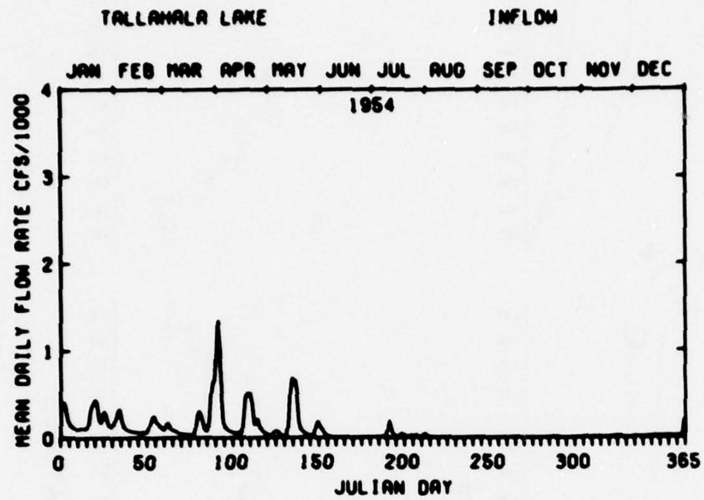
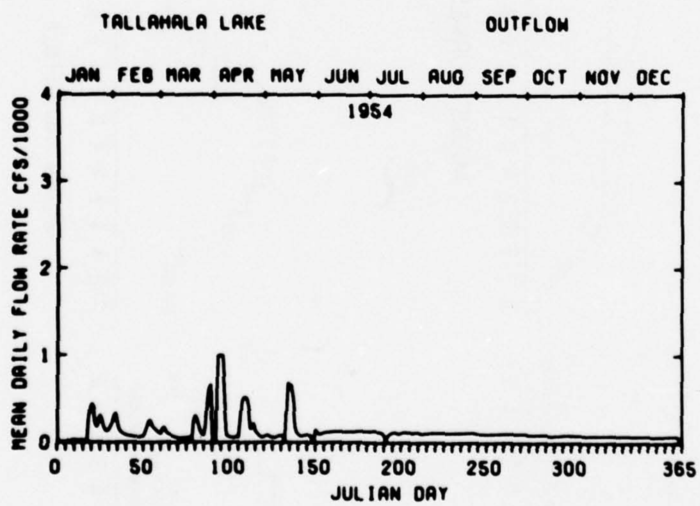
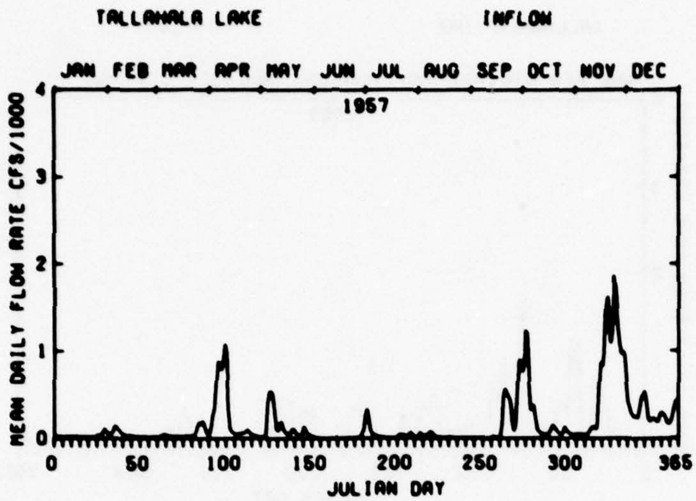
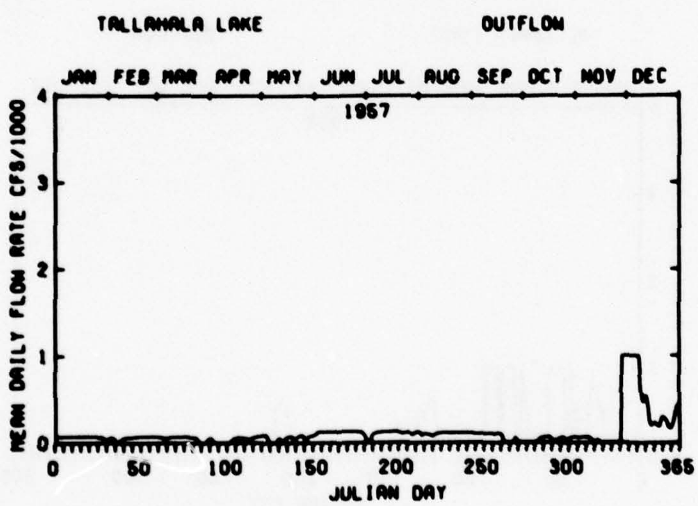




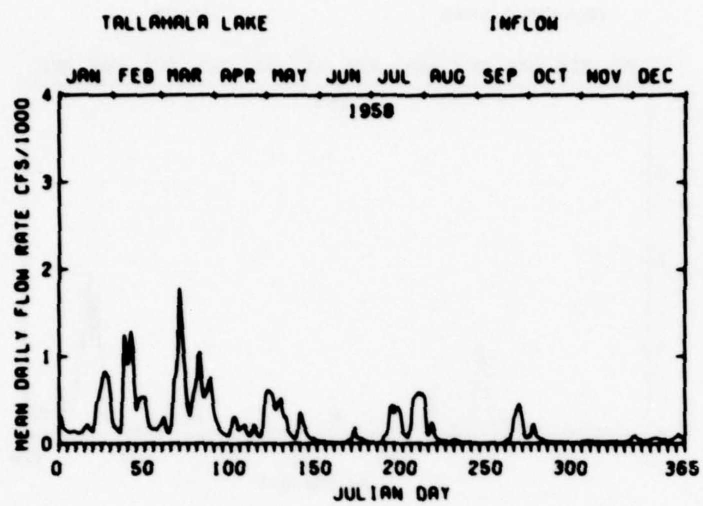
INFLOW AND OUTFLOW
HYDROGRAPHS

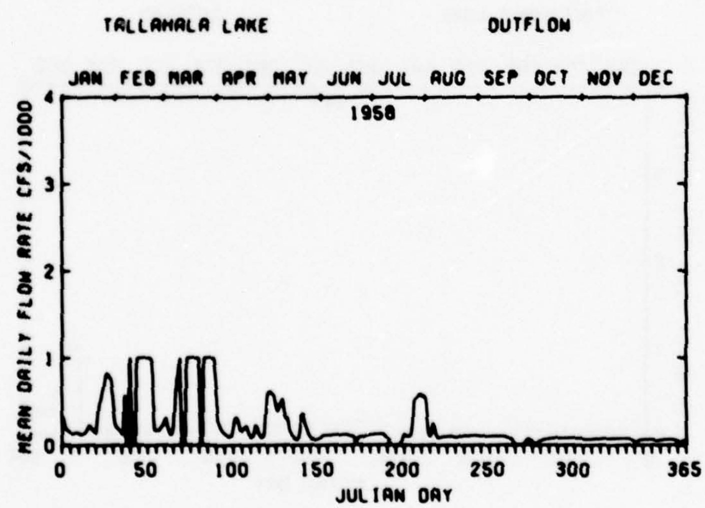
PLATE 2 (SHEET 1 OF 5)





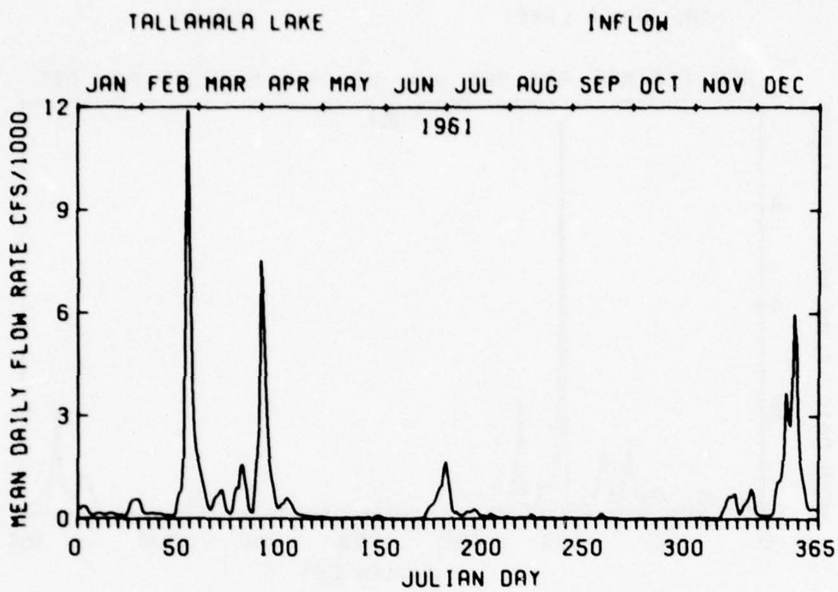
INFLOW AND OUTFLOW
HYDROGRAPHS

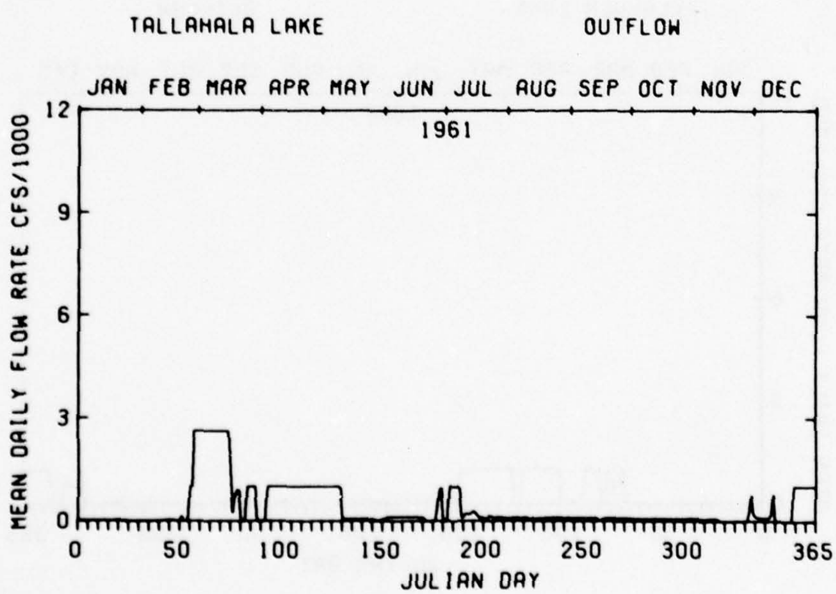




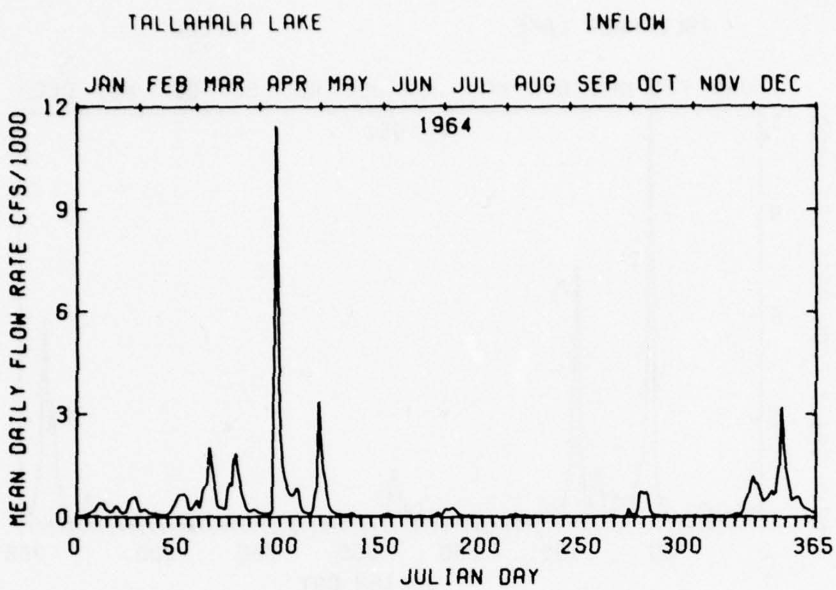
INFLOW AND OUTFLOW
HYDROGRAPHS

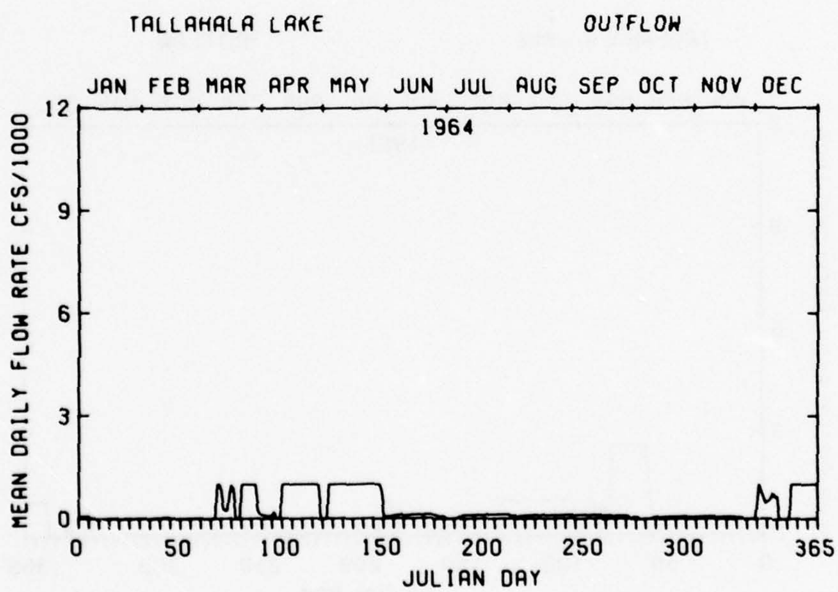
PLATE 2 (SHEET 3 OF 5)





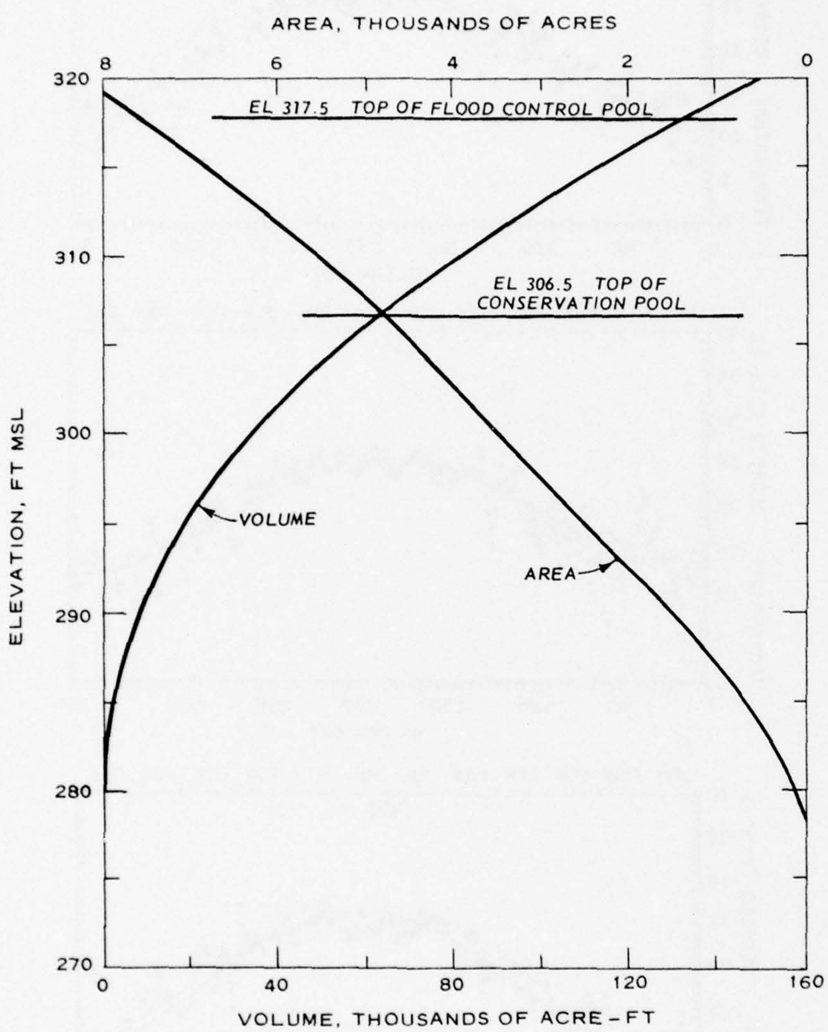
INFLOW AND OUTFLOW
HYDROGRAPHS



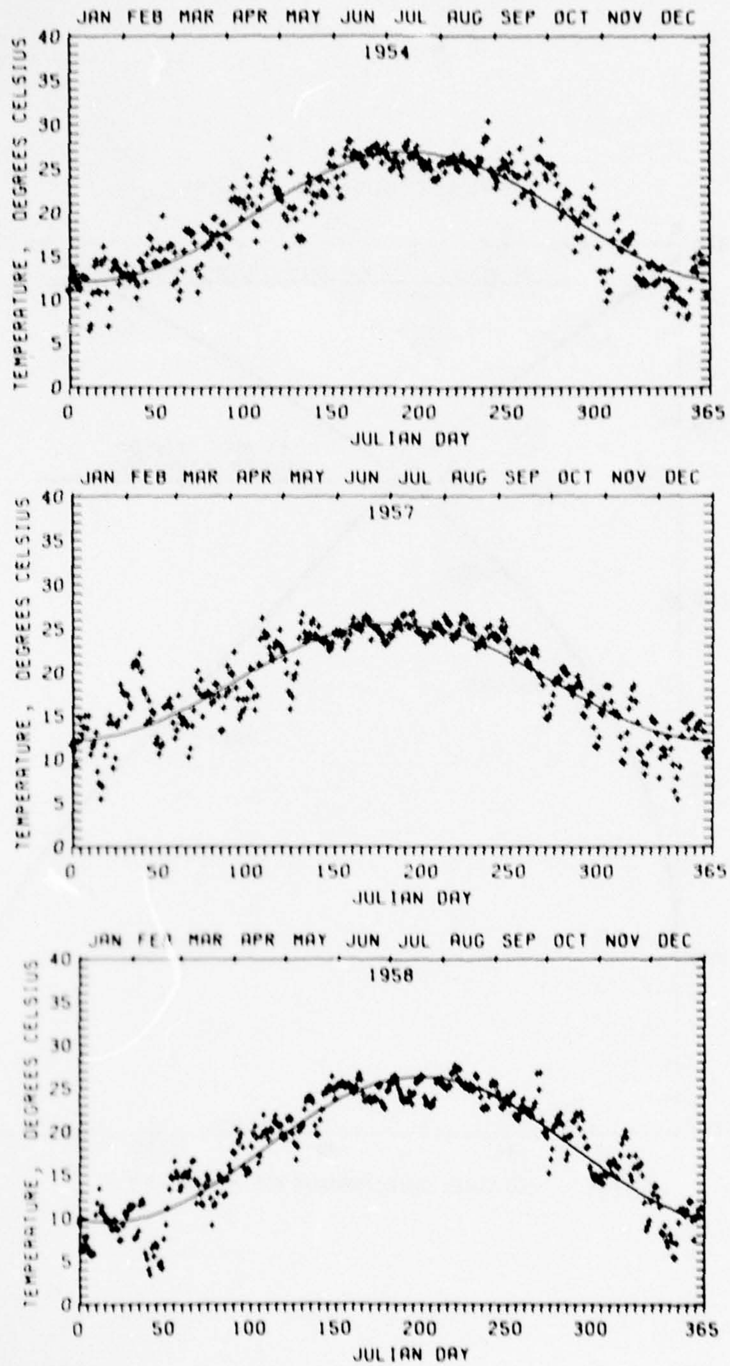


INFLOW AND OUTFLOW
HYDROGRAPHS

PLATE 2 (SHEET 5 OF 5)

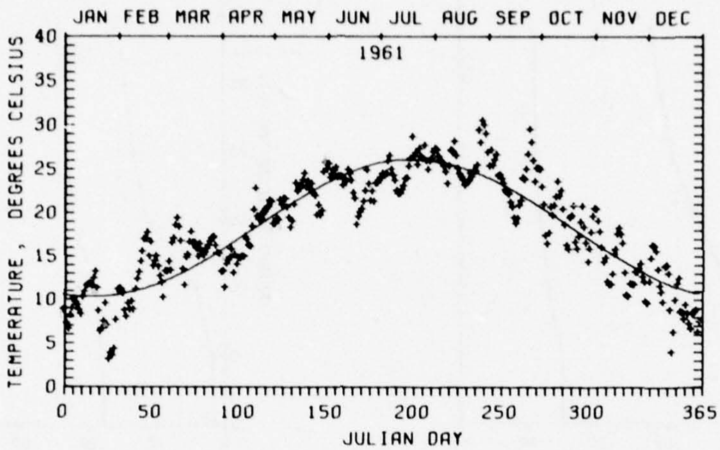


AREA - VOLUME CURVE



COMPUTED INFLOW TEMPERATURES
WITH HARMONIC CURVE FIT
FOR STUDY YEARS

PLATE 4 (SHEET 1 OF 2)



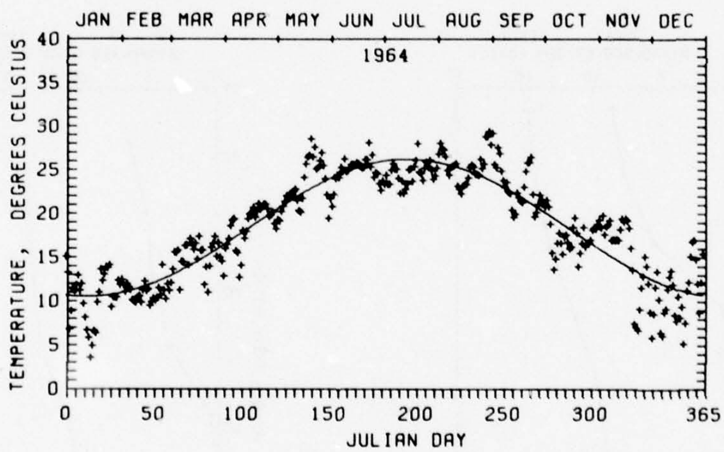
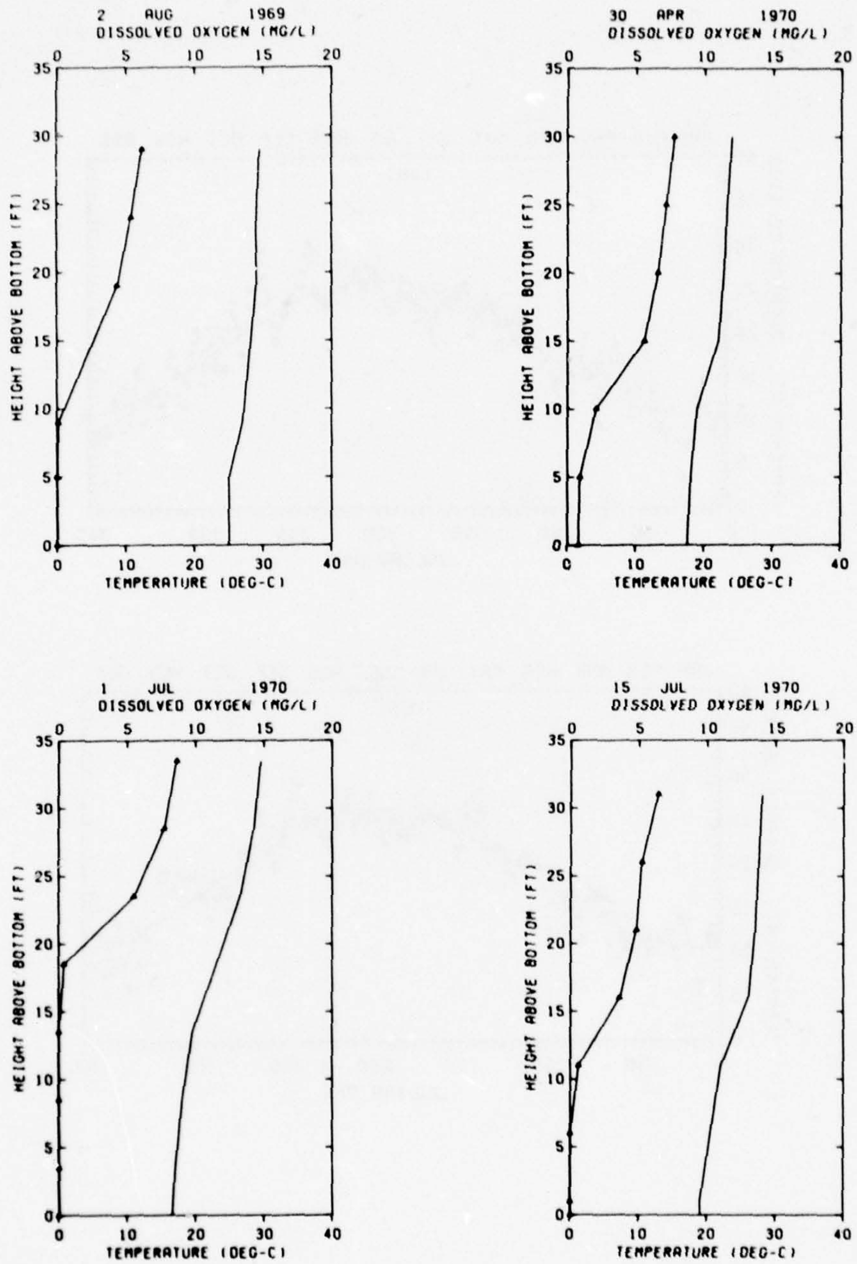


PLATE 4 (SHEET 2 OF 2)



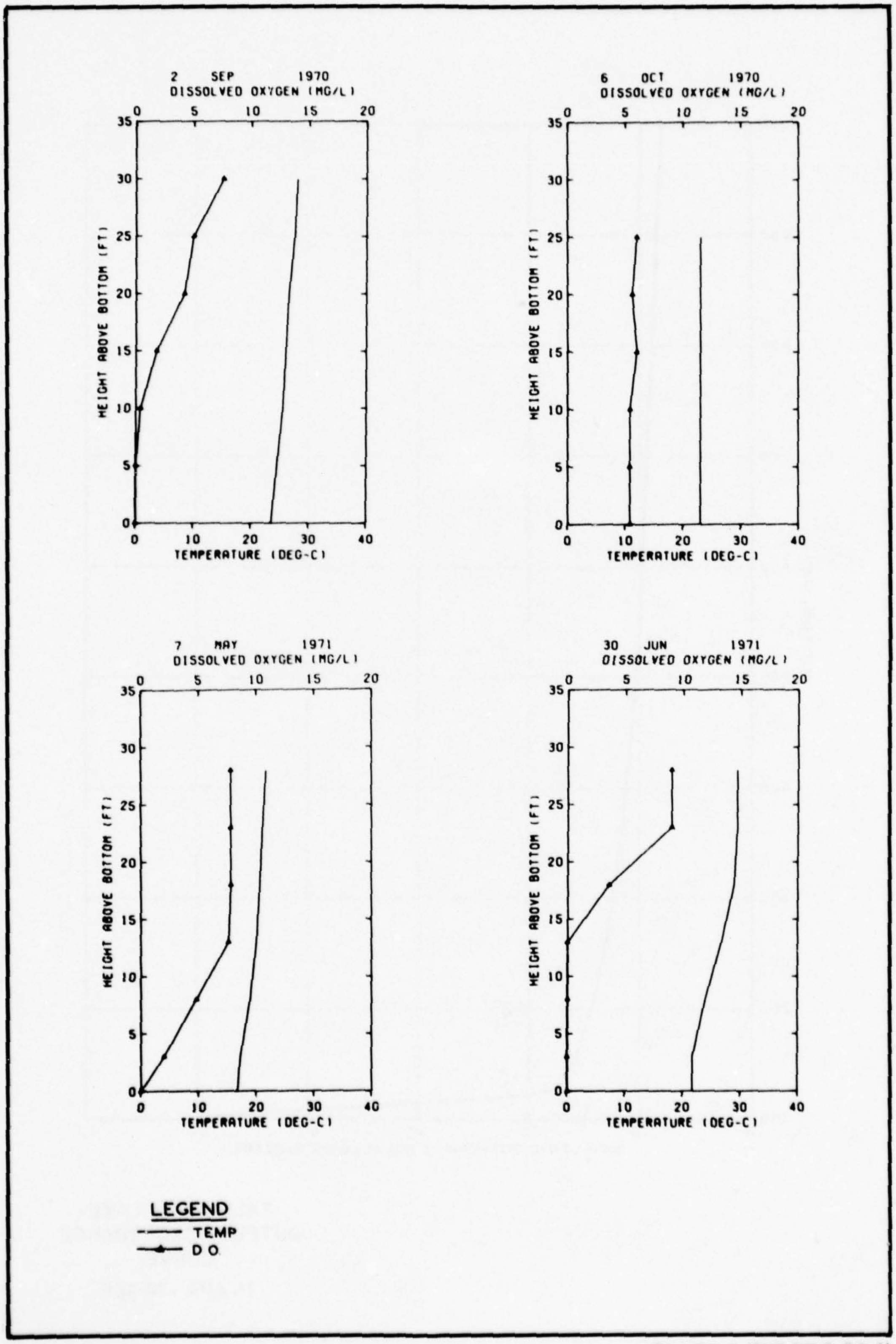
LEGEND

TEMP

DO

OBSERVED OKATIBEE LAKE TEMPERATURES AND DISSOLVED OXYGEN PROFILES

PLATE 5 (SHEET 1 OF 2)



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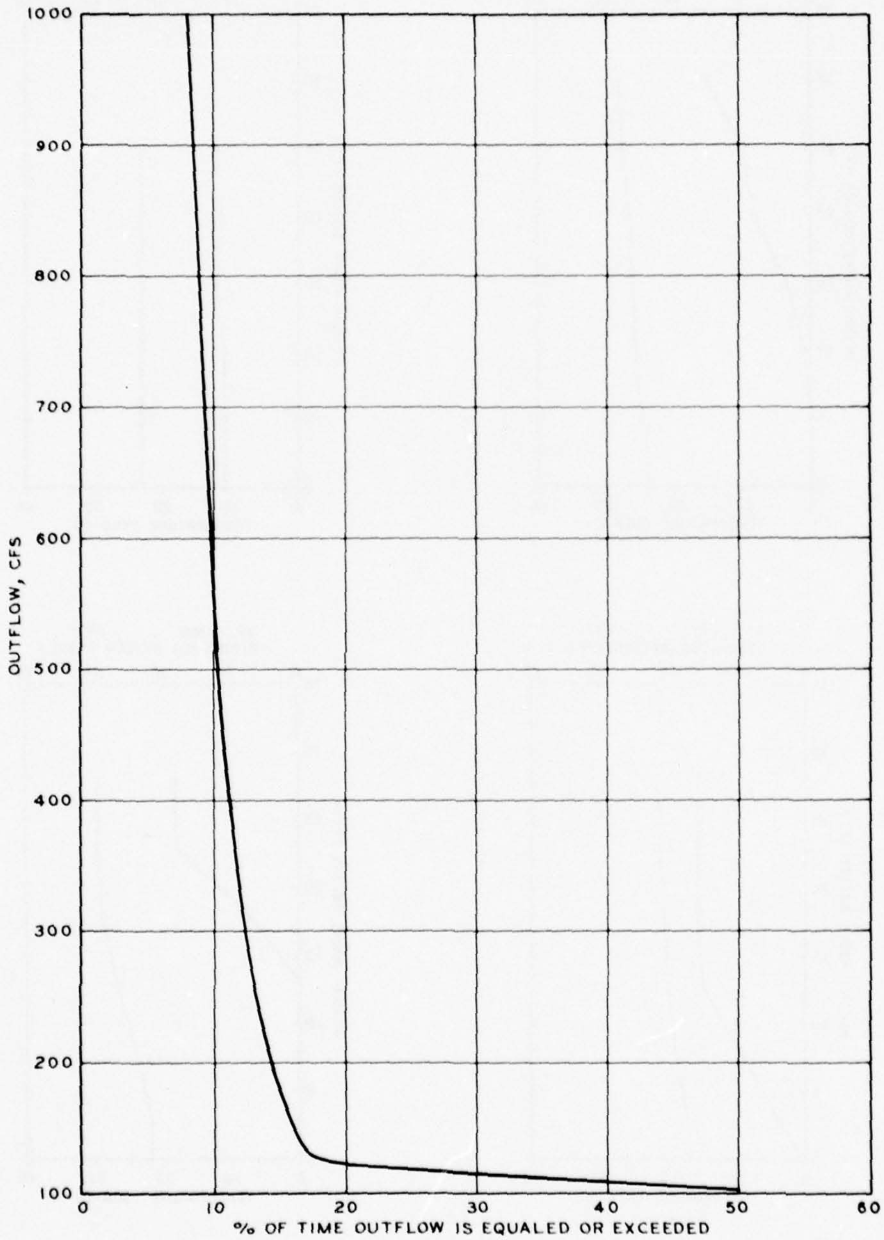
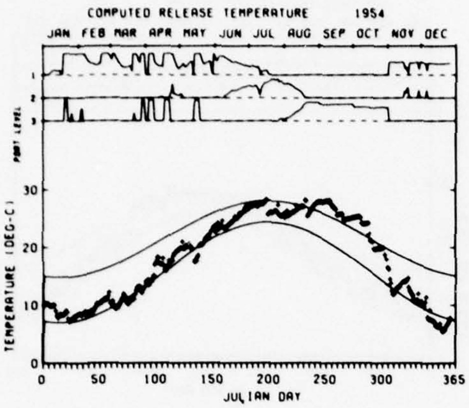


TALLAHALA LAKE
OUTFLOW EXCEEDANCE
CURVE

15 APR - 30 SEP

PLATE 6



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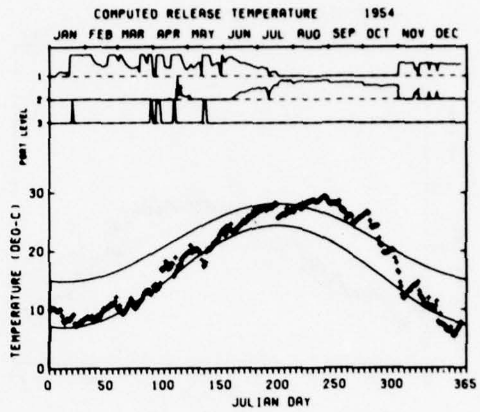

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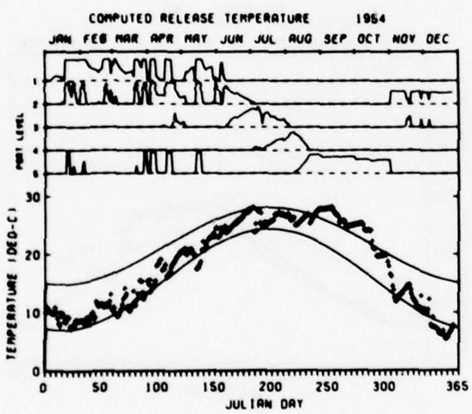

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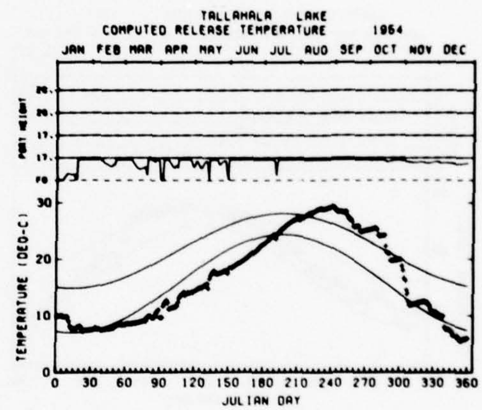


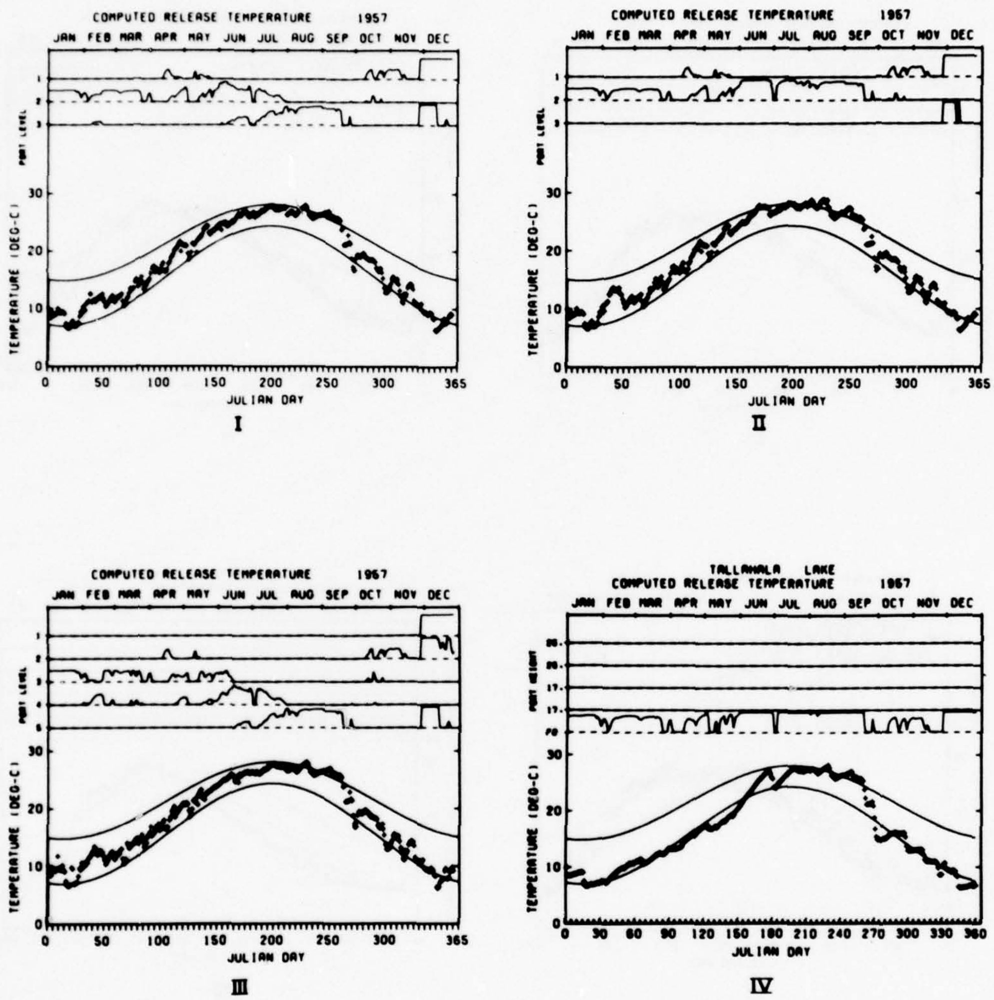
IV

1954

INTAKE TYPE	I	II	III	IV
SEL WITHDRAWAL	YES	YES	YES	NO
PORT HEIGHTS	2-17; 2-26	2-17; 2-26	14, 20, 26, 32	FLOODGATE ONLY
LOW-LEVEL OUTLET	YES	NO	YES	YES

COMPUTED
RELEASE TEMPERATURES

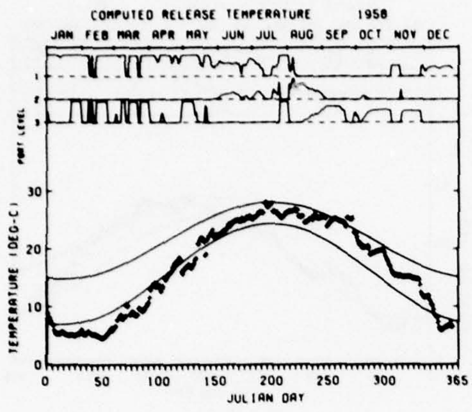
PLATE 7 (SHEET 1 OF 5)



1957

INTAKE TYPE	I	II	III	IV
SEL WITHDRAWAL	YES	YES	YES	NO
PORT HEIGHTS	2-17; 2-26	2-17; 2-26	14, 20, 26, 32	FLOODGATE ONLY
LOW LEVEL OUTLET	YES	NO	YES	YES

PLATE 7 (SHEET 2 OF 5)



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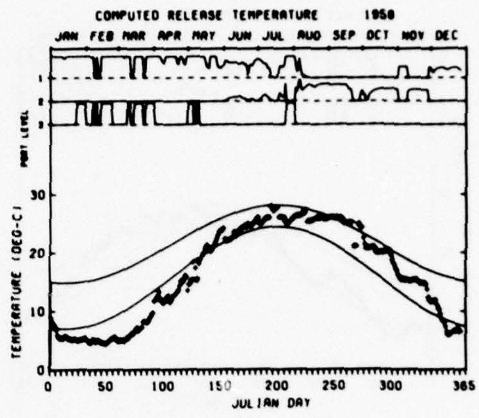

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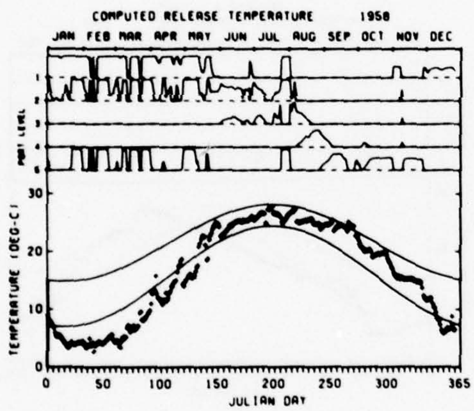

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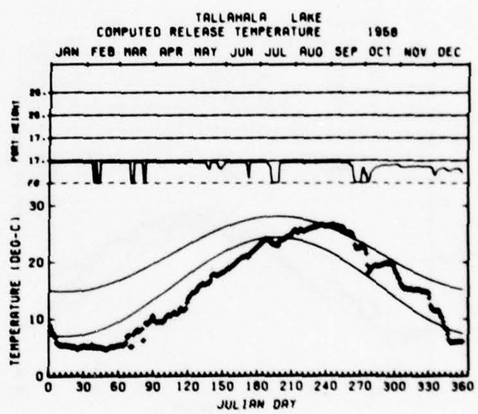
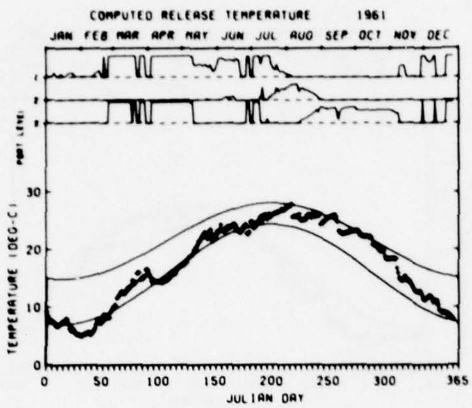


IV

1958

INTAKE TYPE	I	II	III	IV
SEL WITHDRAWAL	YES	YES	YES	NO
PORT HEIGHTS	2-17; 2-26	2-17; 2-26	14, 20, 26, 32	FLOODGATE ONLY
LOW LEVEL OUTLET	YES	NO	YES	YES



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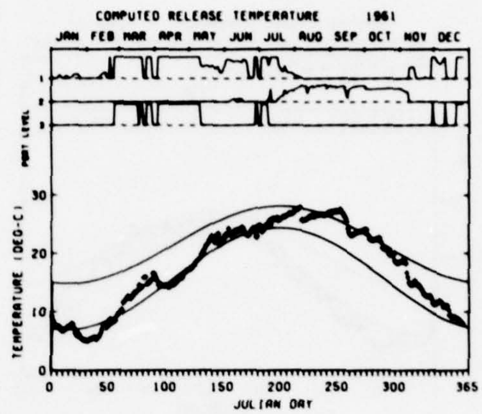

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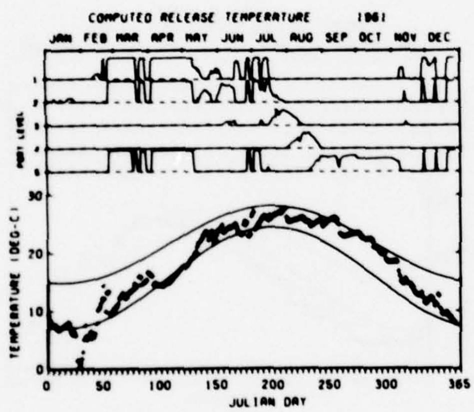

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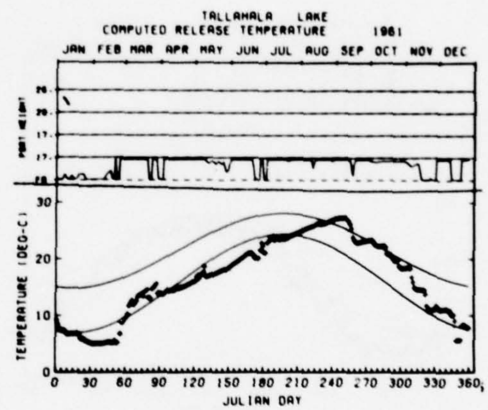
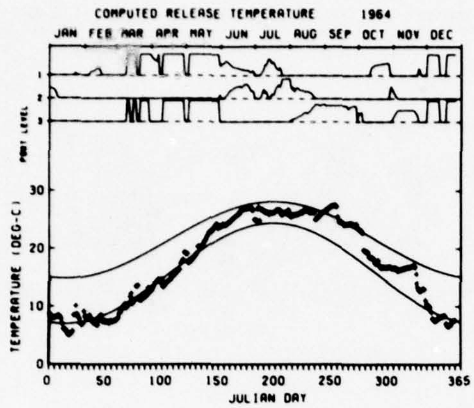


IV

1961

INTAKE TYPE	I	II	III	IV
SEL WITHDRAWAL	YES	YES	YES	NO
PORT HEIGHTS	2-17; 2-28	2-17; 2-28	14, 20, 26, 32	FLOODGATE ONLY
LOW LEVEL OUTLET	YES	NO	YES	YES

PLATE 7 (SHEET 4 OF 5)



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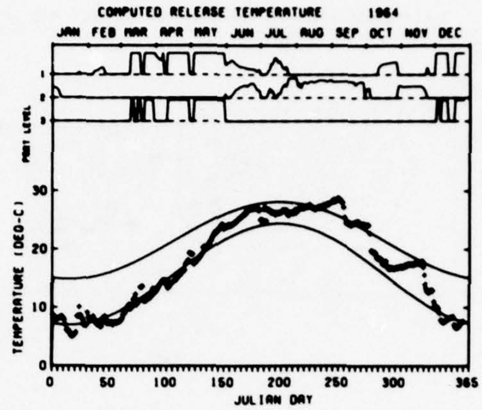

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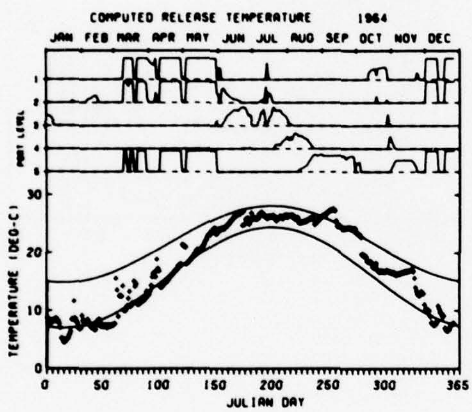

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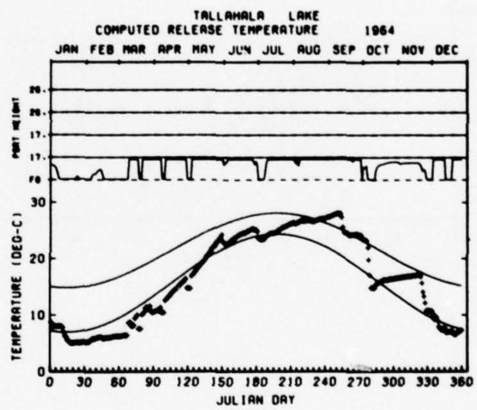
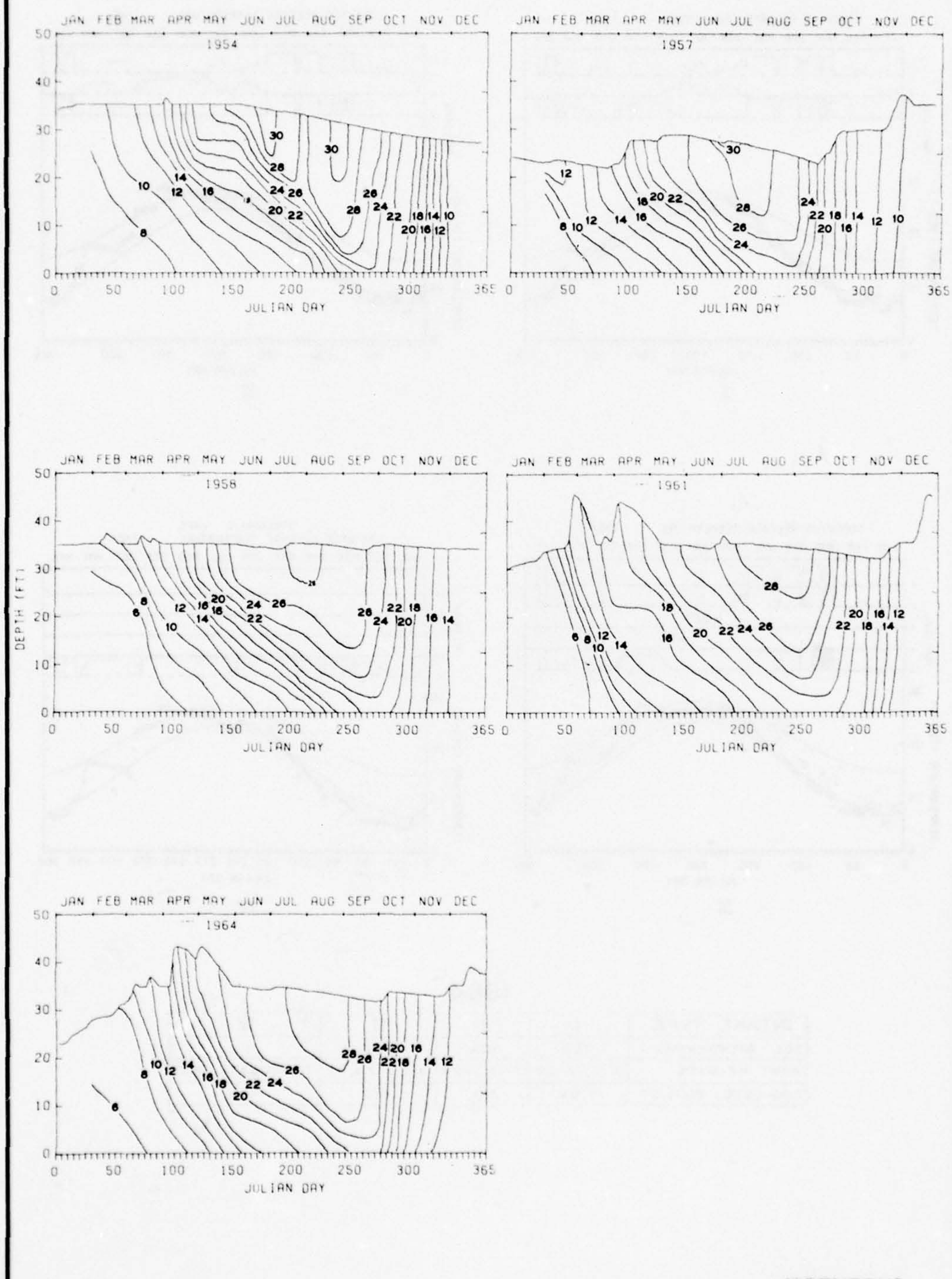


IV

1964

INTAKE TYPE	I	II	III	IV
SEL WITHDRAWAL	YES	YES	YES	NO
PORT HEIGHTS	2-17; 2-28	2-17; 2-28	14, 20, 26, 32	FLOODGATE ONLY
LOW LEVEL OUTLET	YES	NO	YES	YES


1954
1957
1958
1961
1964
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
DEPTH (FT)
JULIAN DAY

ISOTHERMS

APPENDIX A: DISSOLVED OXYGEN

1. The dissolved oxygen (D.O.) content of the reservoir can be defined as the sources minus the sinks. The sources of D.O. in impoundments include photosynthesis in the euphotic zone, atmospheric reaeration, and reservoir inflows. D.O. sinks include respiration of plants and animals, oxygen demand of reservoir inflows, benthic and detritus oxygen demands, and D.O. in reservoir outflows.

2. Observations of actual D.O. profiles in various lakes by Bella,[8*] Carroll and Fruh,[9] and Fontane and Bohan[10] indicate that a portion of the lake below the surface can experience temperature-dependent saturated D.O. conditions. For depths below this saturation zone, the net effect of all D.O. sources and sinks can be represented mathematically by a total D.O. depletion term.

3. The WESTEX model contains a simple method for routing D.O. based on the work of Bella,[8] Carroll and Fruh,[9] and Fontane and Bohan.[10] D.O. is routed in a manner similar to that used for temperature. The processes simulated in the model are advection, surface saturation, internal dispersion, and oxygen depletion. The D.O. routing portion of the WESTEX model is used to evaluate the relative effects of structural design and project operation on the D.O. budget of the lake. The results should not be interpreted as predictions of absolute day-to-day D.O. concentrations. As indicated by Bella,[8] the resultant D.O. predictions do not account for short-term D.O. variations (for example, due to an algal bloom), but rather reflect the progressive D.O. changes that occur with depth over the entire stratification period.

Advection and Internal Dispersion

4. The D.O. content of the inflow and the outflow is evaluated and used to adjust profiles within the lake. An internal mixing mechanism,

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* Raised numerals refer to similarly numbered items in the References at the end of the main text.

based on an analogy of the thermal diffusion process, is applied to the D.O. profile. This internal mixing mechanism simulates the movement of D.O. from the upper to the lower layers of the lake.

Oxygen Depletion

5. Total oxygen depletion rates are determined by plotting D.O. versus time for a given elevation. This depletion rate is a function of all the processes, hydrodynamic and oxygen-consuming, that occur in the reservoir. The WESTEX model accounts for the hydrodynamic processes; therefore, the value of the depletion rate used in the WESTEX model is selected to represent only the oxygen-consuming processes. The depletion rate used in the model is selected such that the D.O. profiles produced by the model will yield total depletion rates which are reasonable in terms of observed data on similar reservoirs.

6. Within the WESTEX model, the depletion rate for D.O., a constant value throughout the entire simulation period, is applied each daily time step to every layer below the surface saturation zone.

Surface Saturation

7. As indicated previously, observed D.O. profile data have shown the existence of a surface saturation zone. Many factors influence the characteristics of this zone. Considerable analysis of many lake profiles is needed for a general determination of saturation zone thickness and percentage of D.O. saturation within this zone. The values used for a given project study should be based on observed data from similar lakes.

Dissolved Oxygen Data

8. Data on the D.O. content of flow in Tallahala Creek were available from the preimpoundment study[11] of the project. Based on these data, two regression equations were developed to predict the D.O.

content of the inflow to Tallahala Creek Lake:

$$D.O._{inflow} = -2.88 + 1.14\ D.O._{sat} \quad \text{for } T > 7°C$$

and

$$D.O._{inflow} = 0.90 \times D.O._{sat} \quad \text{for } T \le 7°C$$

where

$D.O._{inflow}$ = inflow D.O. content, mg/ℓ

T = stream temperature, °C

$D.O._{sat}$ = temperature-dependent saturated D.O. content, mg/ℓ

The saturated D.O. content was computed by

$$D.O._{sat} = \frac{1}{0.0677 + 0.00208T}$$

Daily values of the computed D.O. content of the inflow are shown in Plate A1 for each of the five study years. The net D.O. contributed by inflow is the inflowing D.O. content decreased by an amount which represents D.O. depletion due to the travel time within the lake required for the inflow current to reach the dam. The travel time for an inflow current to reach the dam was not known for Tallahala Creek Lake. For these simulations, the depletion of D.O. due to travel time was neglected and it was assumed that the net D.O. contributed by inflow was equal to the computed inflow D.O. content.

9. Observed thermal and D.O. profile data were available for four Mississippi lakes: Okatibee Lake (1969-71), Enid Lake (1971-72), Sardis Lake (1968-71), and Grenada Lake (1970-72). Analysis of these profile data yielded a range of values for total depletion rates, surface saturation percentages, and depths to which saturation extends.

Dissolved Oxygen Simulations

10. Simulations were conducted to evaluate D.O. conditions within and downstream of Tallahala Creek Lake. The intake configuration used was the type II, as discussed previously. Five D.O. conditions were

simulated using different depletion rates, surface saturation percentages, and depths to which saturation extends. The values used represent the range of values determined from the observed data on the Mississippi lakes. The input values used are shown in Table A1. Plate A2 shows D.O. content of flow entering the intake structure for each of the five study years for all five D.O. conditions. Plate A3 shows D.O. profiles within Tallahala Creek Lake for each of the five study years for all five D.O. conditions. Analysis of the predicted D.O. profiles (Plate A3) yields total depletion rates (0.05-0.12) which are within the range of the observed data on the existing Mississippi lakes.

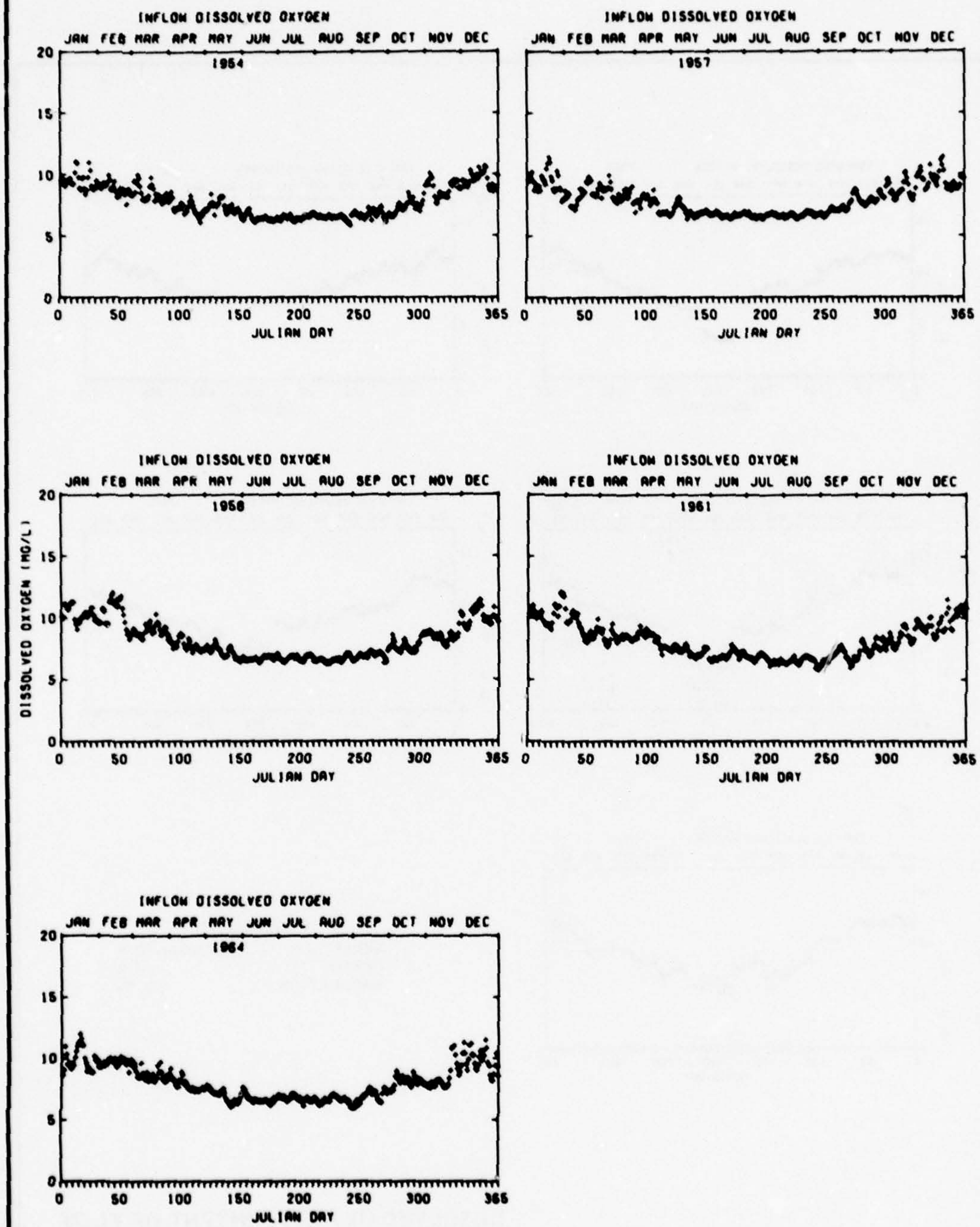
11. The mathematical model computes a value for the D.O. content of the withdrawal as it enters the outlet structure. It is known that reaeration can occur as the result of flow discharging under the regulating gate and through the conduit and stilling basin. Reaeration data from four northern Mississippi impoundments (Enid, Sardis, Grenada, and Arkabutla Lakes) were readily available and were used to develop general information regarding D.O. uptake. Plate A4 shows the percentage change in D.O. saturation through the outlet works and stilling basin as a function of the initial percentage of D.O. saturation of the flow withdrawn from these reservoirs. Plates A5 and A6 show schematic representations of the outlet works at the four northern Mississippi impoundments. Plate A7 shows a schematic representation of the Tallahala Creek Lake outlet works. Since the outlet works and stilling basins at these northern Mississippi impoundments are different from the outlet works and stilling basin of the proposed Tallahala Creek Lake, the data from Plate A4 should not be interpreted as a prediction of reaeration for Tallahala Creek Lake. Rather these data are intended to show that the D.O. content of reservoir outflow can be substantially increased as the flow passes through the outlet works and stilling basin, unless the flow was initially almost fully saturated. Recent prototype tests at Beltzville Dam in Pennsylvania[12] yielded similar results, that is, considerable increases in release D.O. content, and additionally showed that the predominance of reaeration occurred in the outlet conduit immediately downstream of the water-quality control gate. Calculations performed by

SAM[13] for the Tallahala Creek Lake outlet works also indicated that reaeration of flow passing the outlet works would be substantial. Finally, although many variables affect the reaeration potential of the flow, reaeration is associated primarily with flow turbulence. Turbulence is characteristic in a hydraulic jump. A previous hydraulic model investigation[14] conducted at WES indicated that a hydraulic jump will be present in the Tallahala Creek Lake stilling basin for flows greater than 150 cfs, and for lesser flows the hydraulic jump will occur within the outlet conduit. Additionally, the regulating gate will induce turbulence in the flow downstream of the gate, even for very low flows. Based on the above considerations, it is expected that the flow passing through the Tallahala Creek Lake outlet works will sufficiently reaerate to provide acceptable levels of D.O. (5 mg/ℓ minimum) in the release immediately downstream of the structure, regardless of the D.O. content of the flow entering the outlet works.

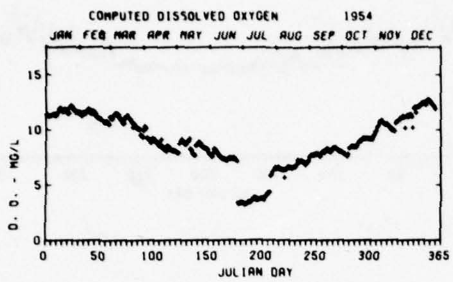
Table A1

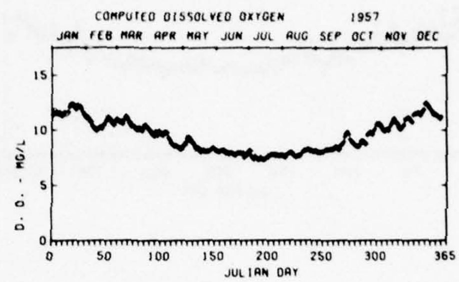
Condition	Depletion Rate	Surface Saturation percent	Saturation Depth
1	0.05	100	1°C*
2	0.12	100	1°C
3	0.12	100	5 ft
4	0.12	80	5 ft
5	0.20	100	1 ft

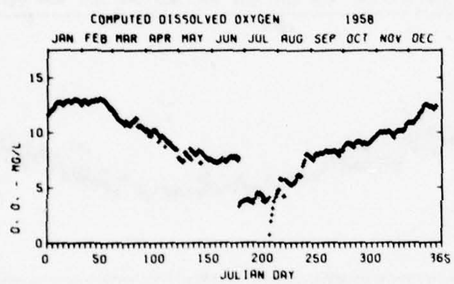
* 1°C is the depth at which the temperature is 1°C less than the surface temperature.

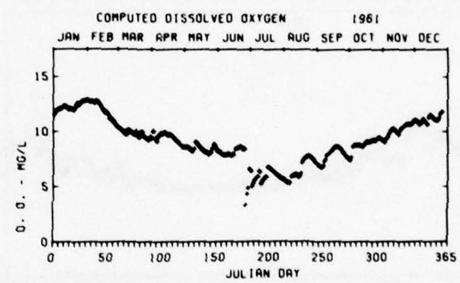


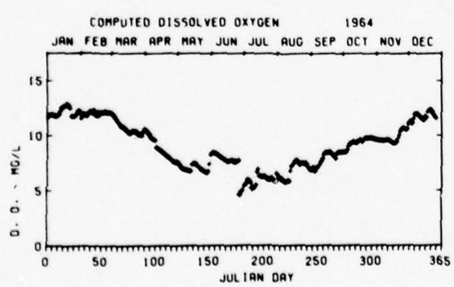
INFLOW DISSOLVED OXYGEN









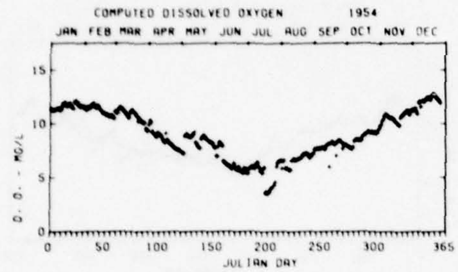


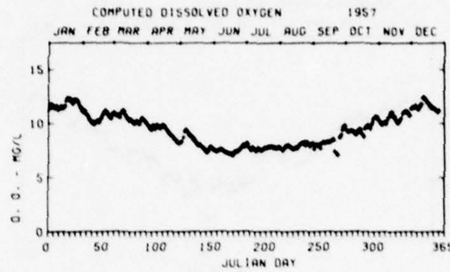
CONDITION 2

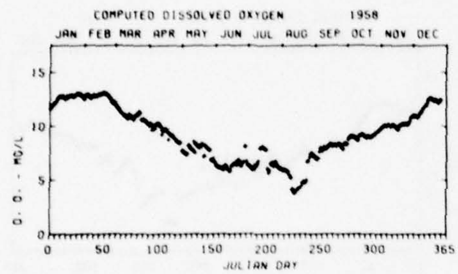
DEPLETION ...... 0.12 MG/L/DAY
DEPTH .... 1° C
SATURATION .... 100 %

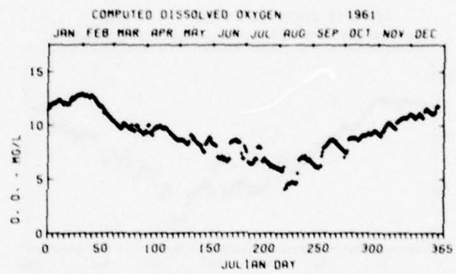
DISSOLVED OXYGEN CONTENT OF FLOW ENTERING INTAKE STRUCTURE

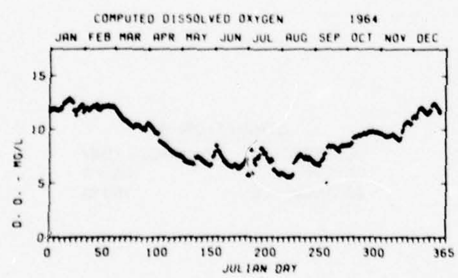
PLATE A2 (SHEET 1 OF 5)







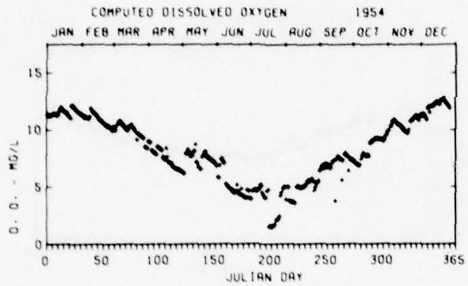


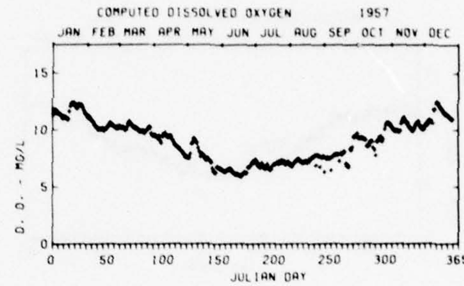


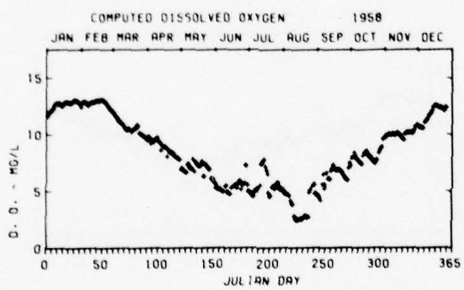
CONDITION 2

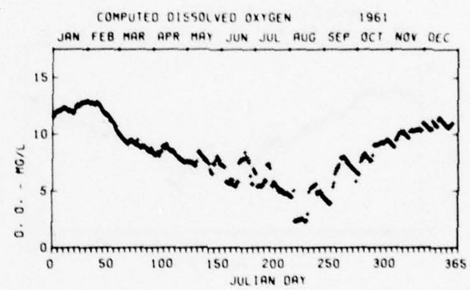
DEPLETION ..... 0.12 MG/L/DAY
DEPTH .... 1°C
SATURATION .... 100 %

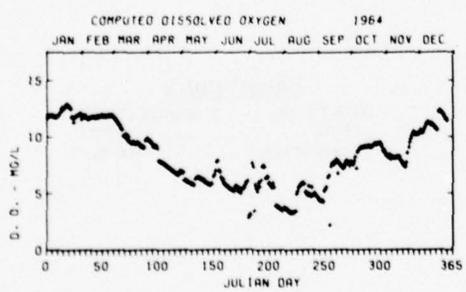
PLATE A2 (SHEET 2 OF 5)







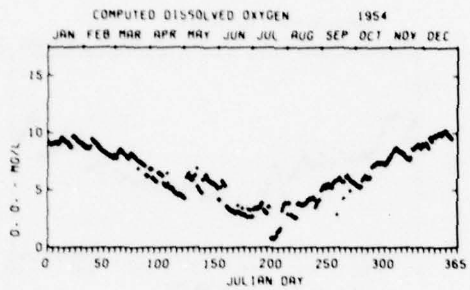


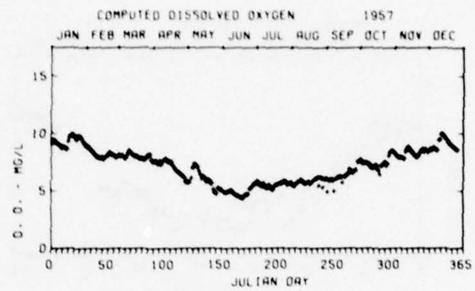


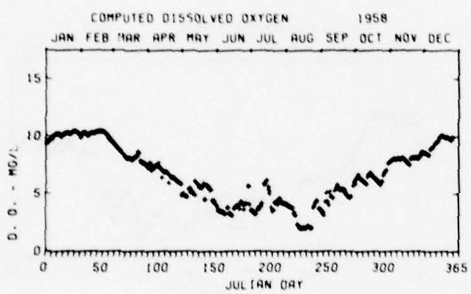
CONDITION 3

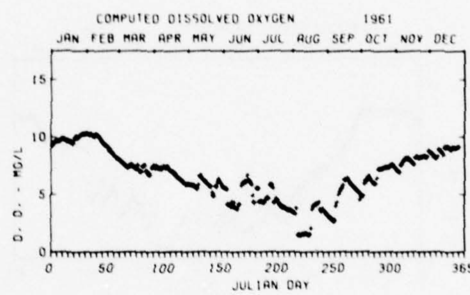
DEPLETION ...... 0.12 MG/L/DAY
DEPTH .... 50 FT
SATURATION 100%

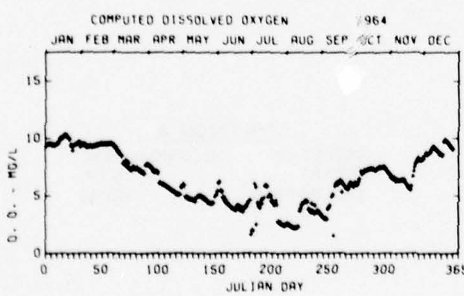
PLATE A2 (SHEET 3 OF 5)







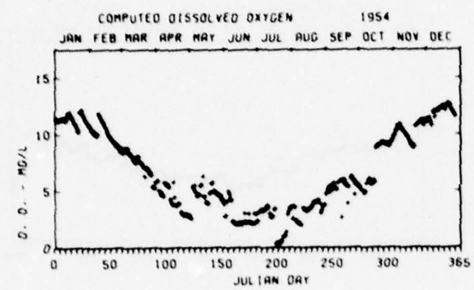


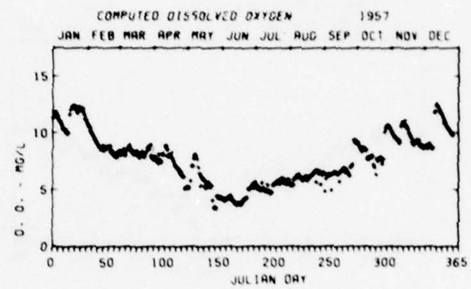


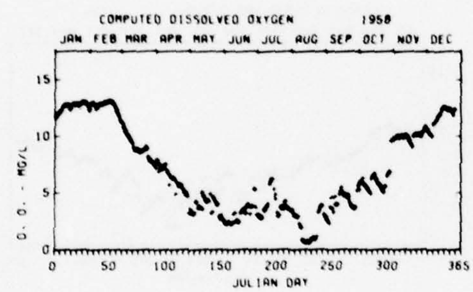
CONDITION 4

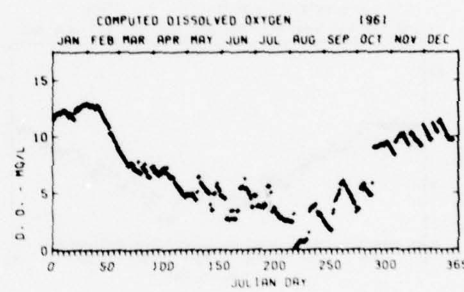
DEPLETION ...... 0.12 MG/L/DAY
DEPTH .... 5.0 FT
SATURATION 80%

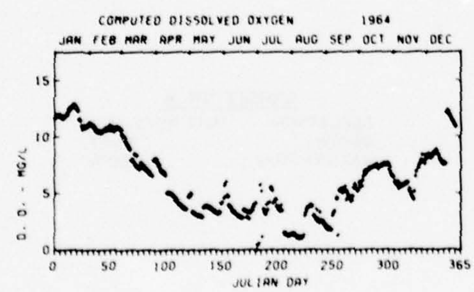
PLATE A2 (SHEET 4 OF 5)









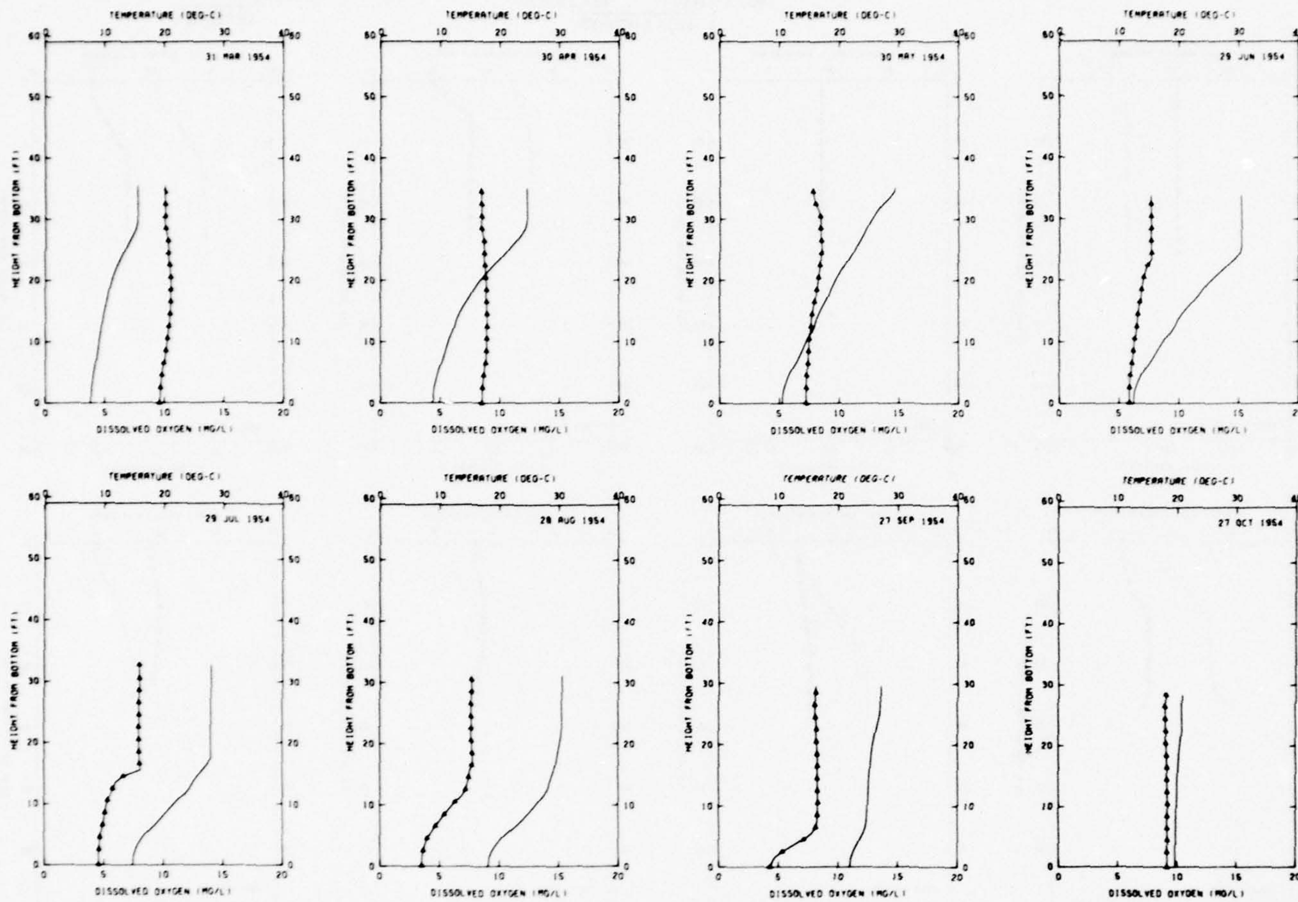


CONDITION 5

DEPLETION ...... 0.20 MG/L/DAY
DEPTH .... 1.0 FT
SATURATION .... 100 %

PLATE A2 (SHEET 5 OF 5)

STUDY YEAR 1954

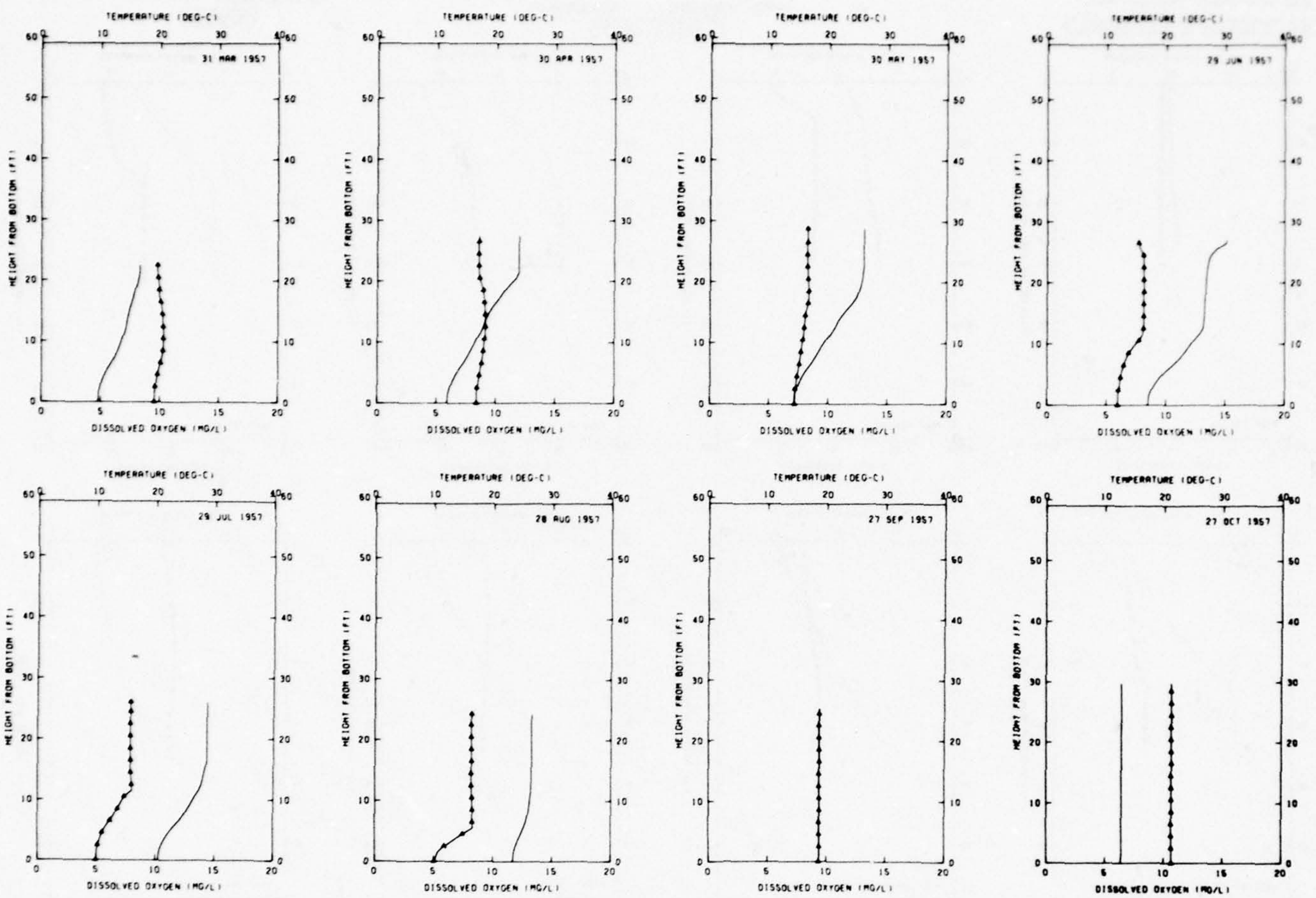


LEGEND
TEMPERATURE
D.O.

CONDITION 1
DEPLETION ..... 0.05 MG/L/DAY
DEPTH ..... 1° C
SATURATION 100%

COMPUTED DISSOLVED OXYGEN PROFILES

STUDY YEAR 1957



LEGEND

- TEMPERATURE (solid line)
- D.O. (line with dots)

CONDITION 1

DEPLETION ..... 0.05 MG/L/DAY
DEPTH ..... 1°C
SATURATION 100%

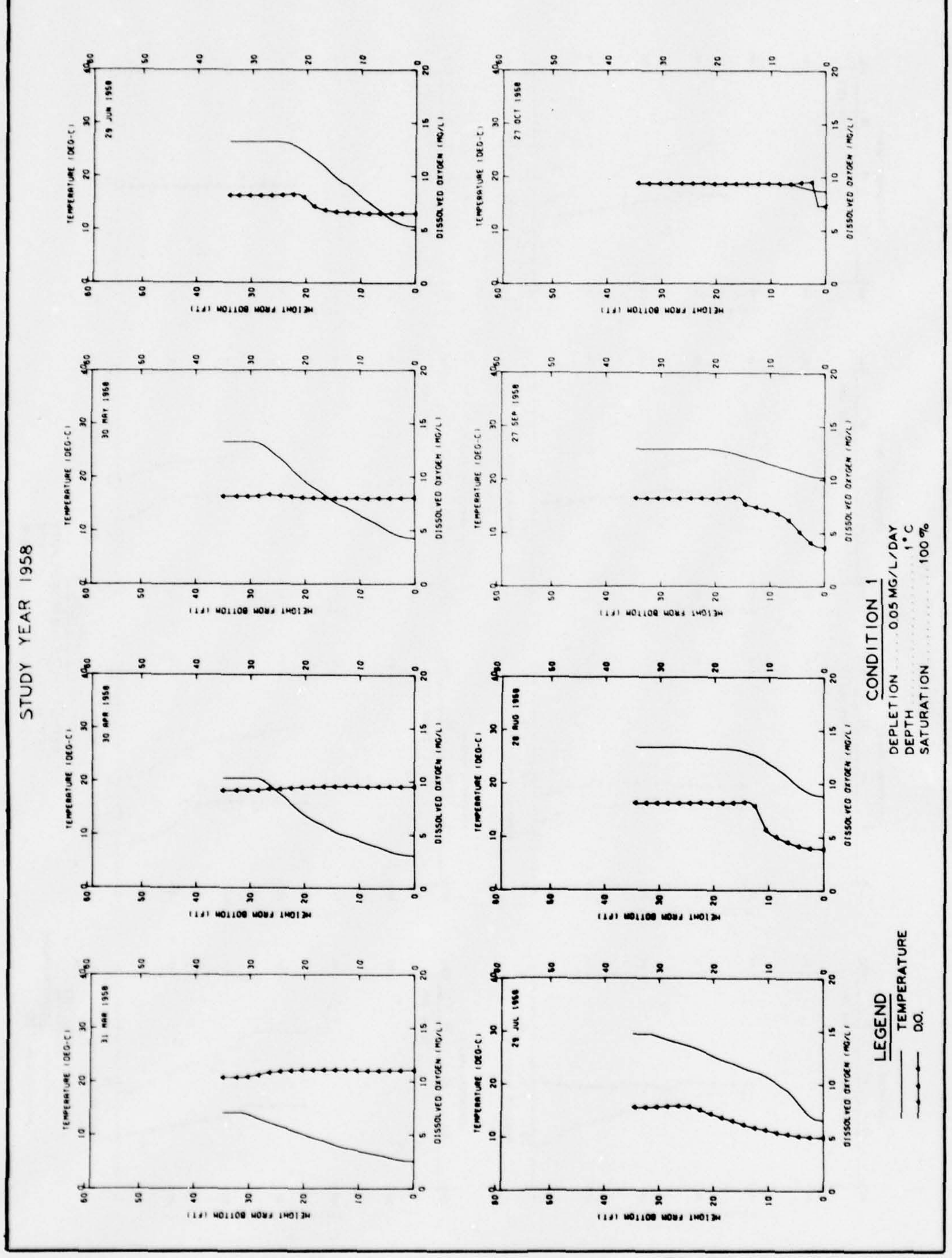


PLATE A3 (SHEET 3 OF 25)

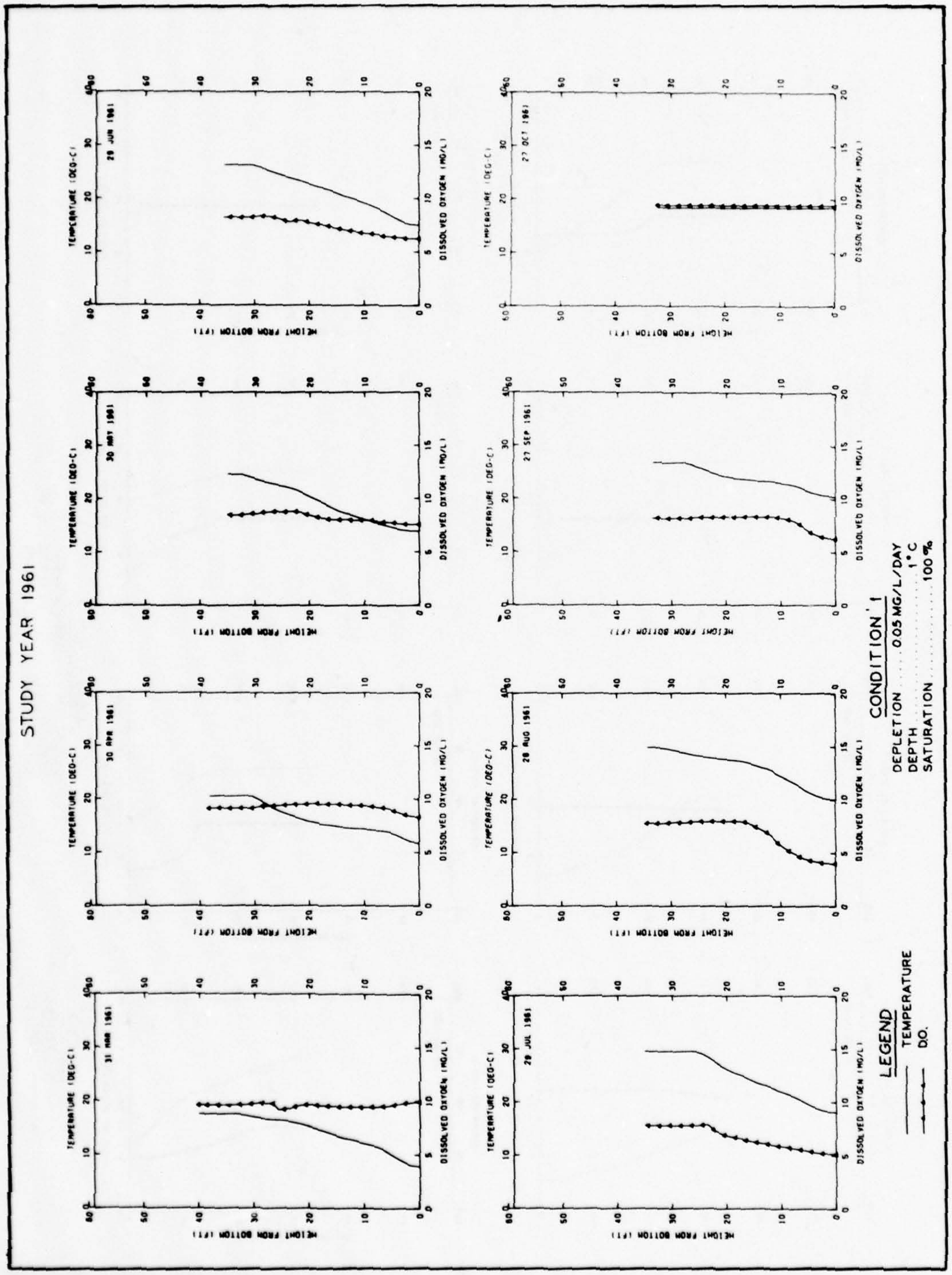
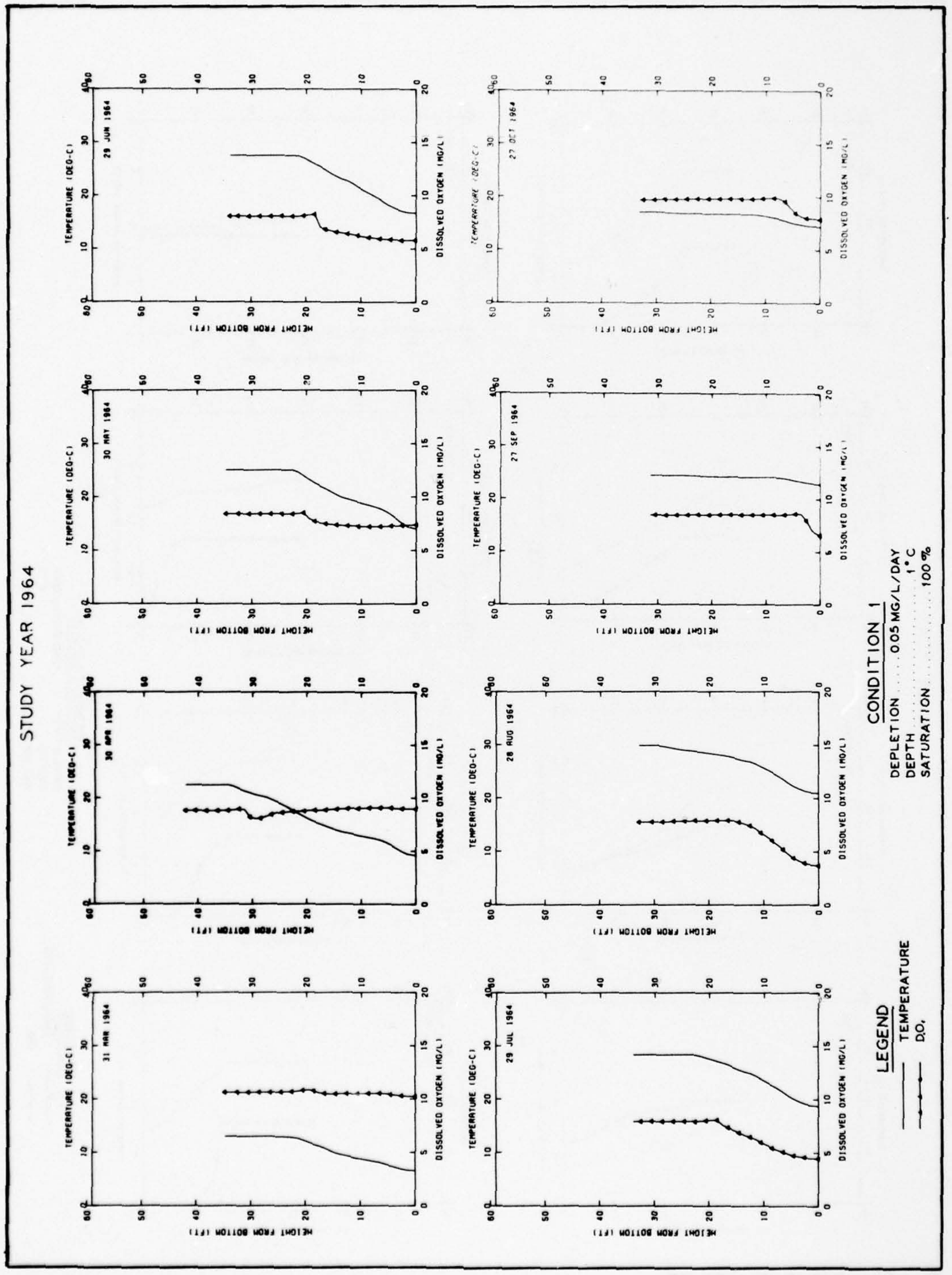


PLATE A3 (SHEET 4 OF 25)



STUDY YEAR 1964
31 MAR 1964
30 APR 1964
30 MAY 1964
29 JUN 1964
29 JUL 1964
28 AUG 1964
27 SEP 1964
27 OCT 1964
TEMPERATURE (DEG-C)
DISSOLVED OXYGEN (MG/L)
HEIGHT FROM BOTTOM (FT)
LEGEND
TEMPERATURE
D.O.
CONDITION 1
DEPLETION .005 MG/L/DAY
DEPTH 1°C
SATURATION 100%

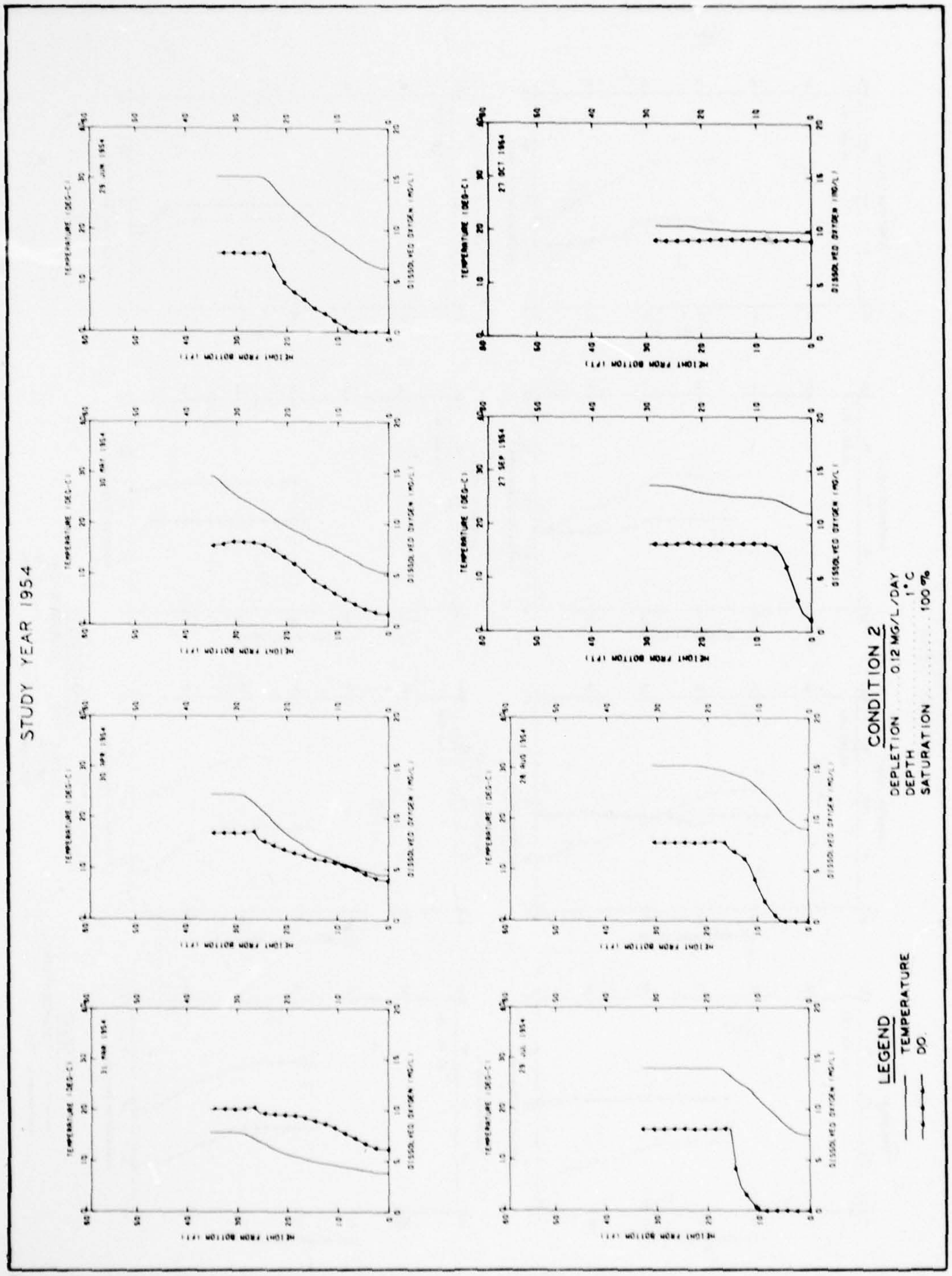
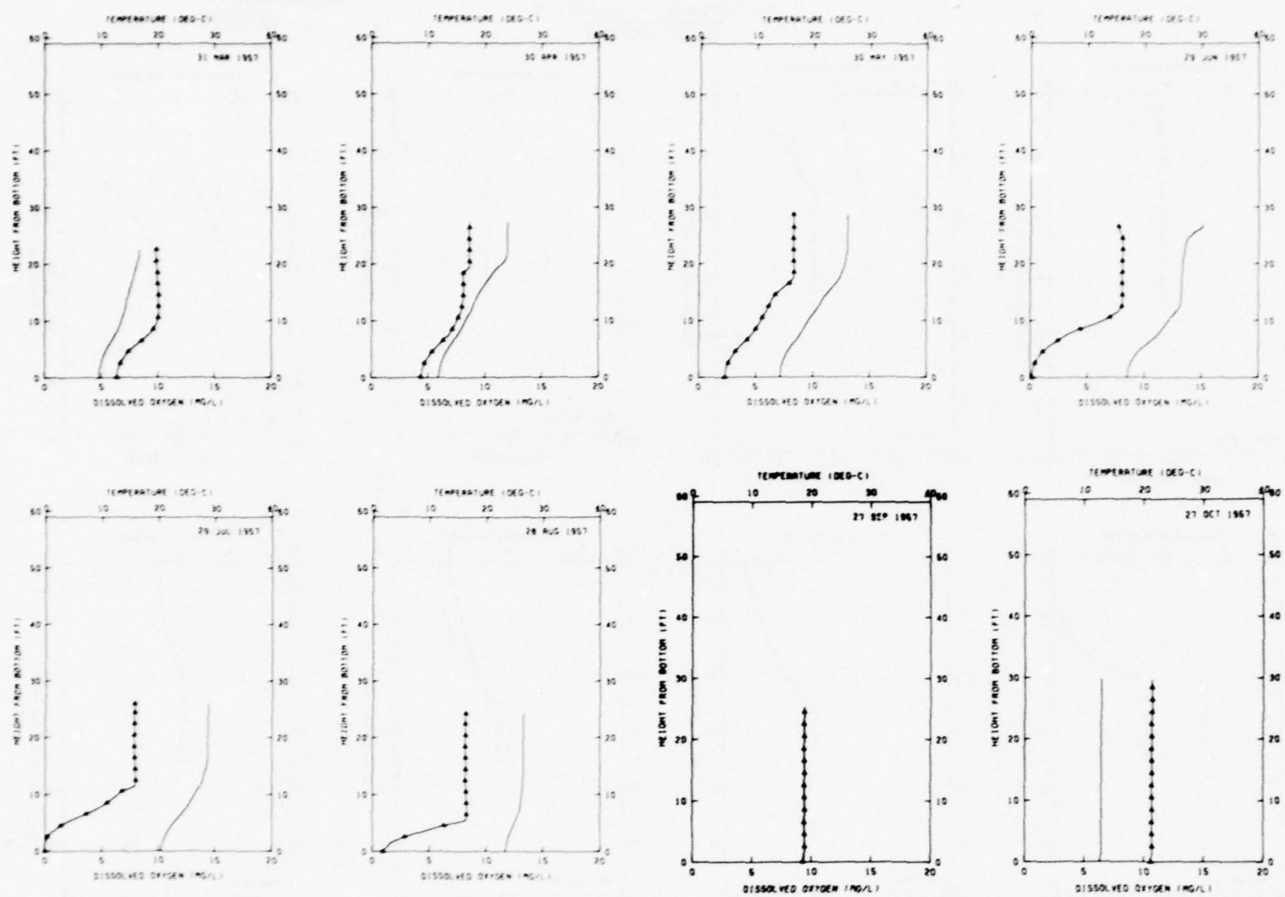


PLATE A3 (SHEET 6 OF 25)

STUDY YEAR 1957



LEGEND
TEMPERATURE
DO.

CONDITION 2
DEPLETION ..... 0.12 MG/L/DAY
DEPTH ..... 1°C
SATURATION 100%

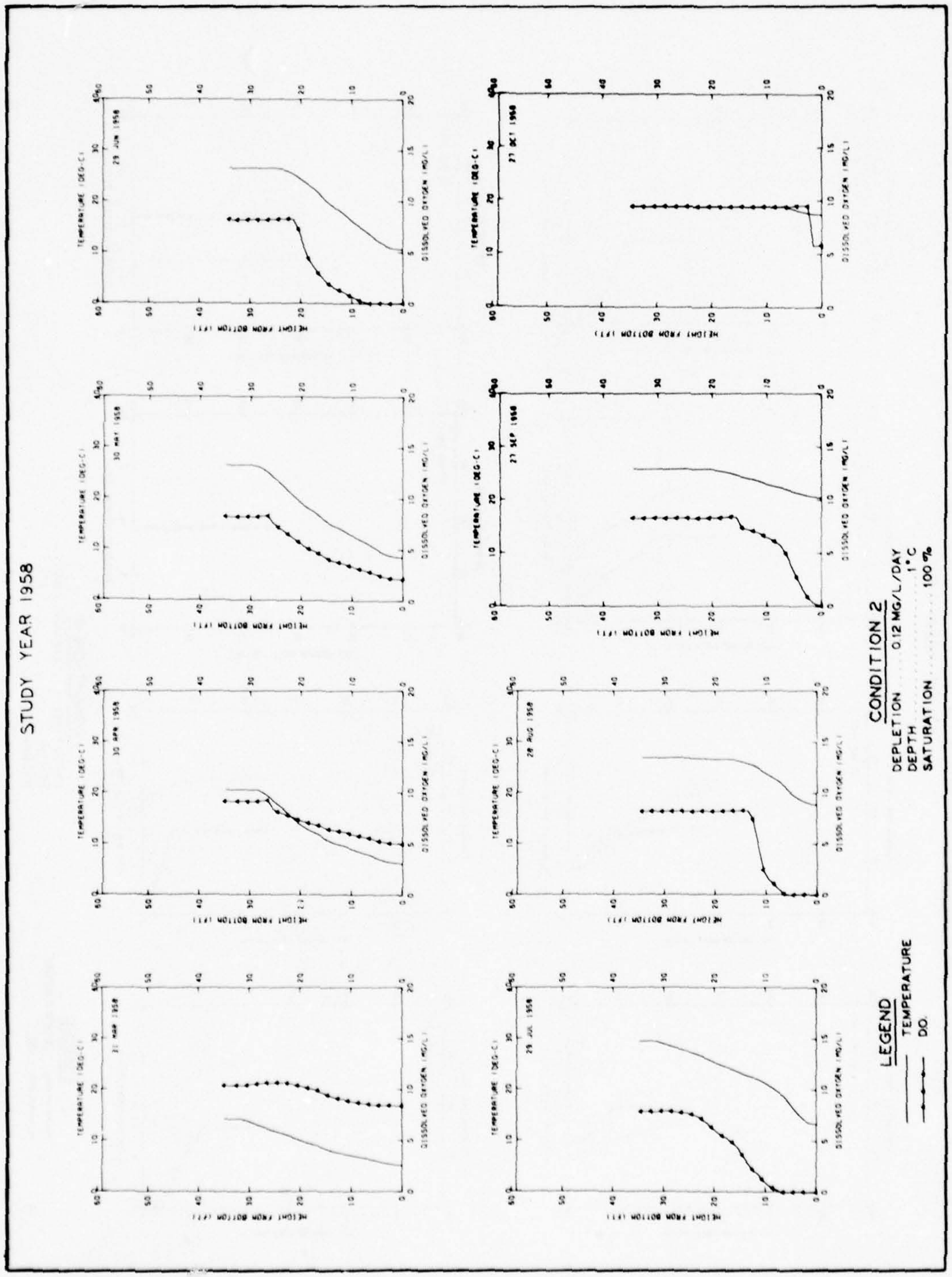


PLATE A3 (SHEET 8 OF 25)

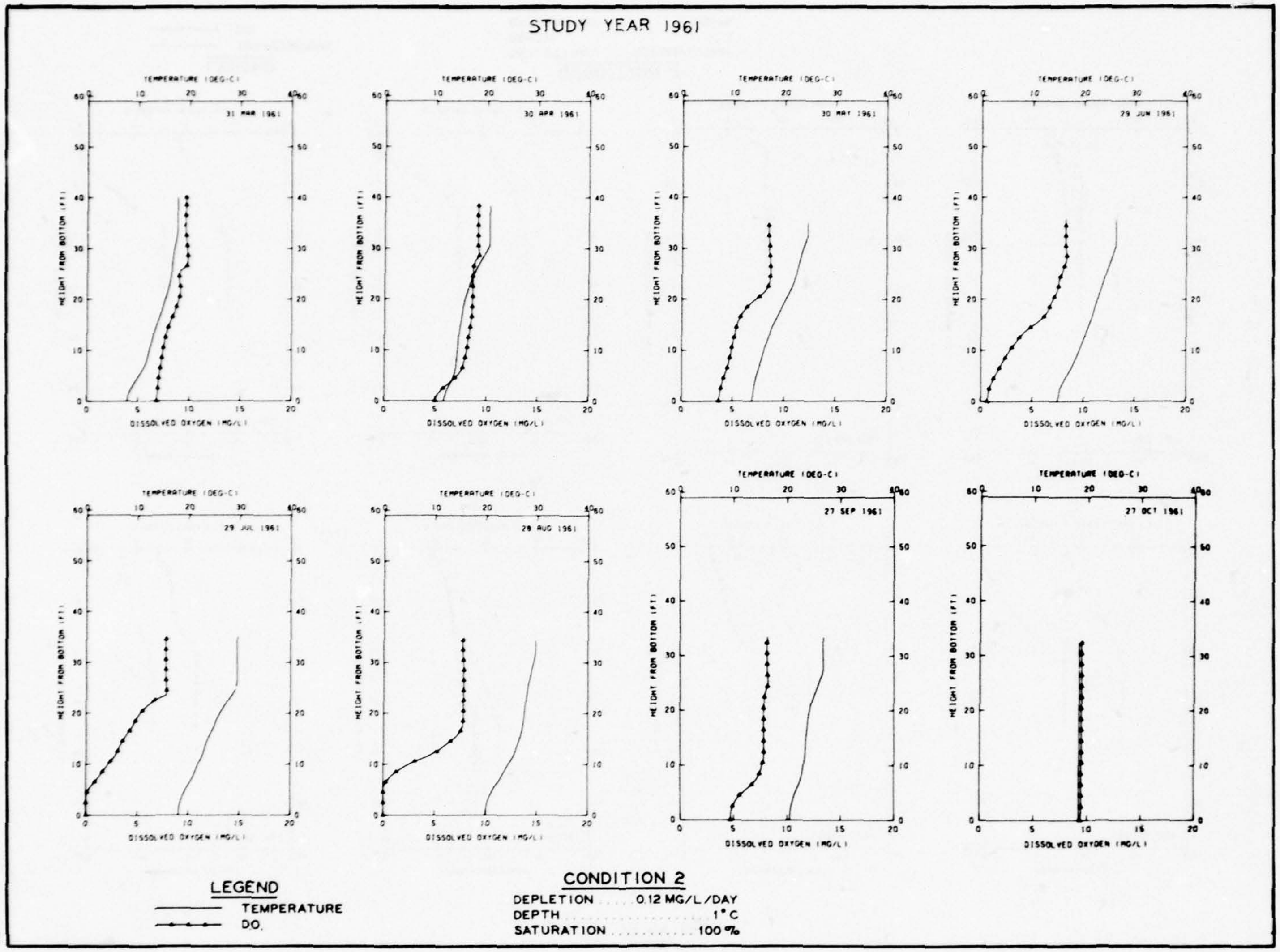


PLATE A3 (SHEET 9 OF 25)

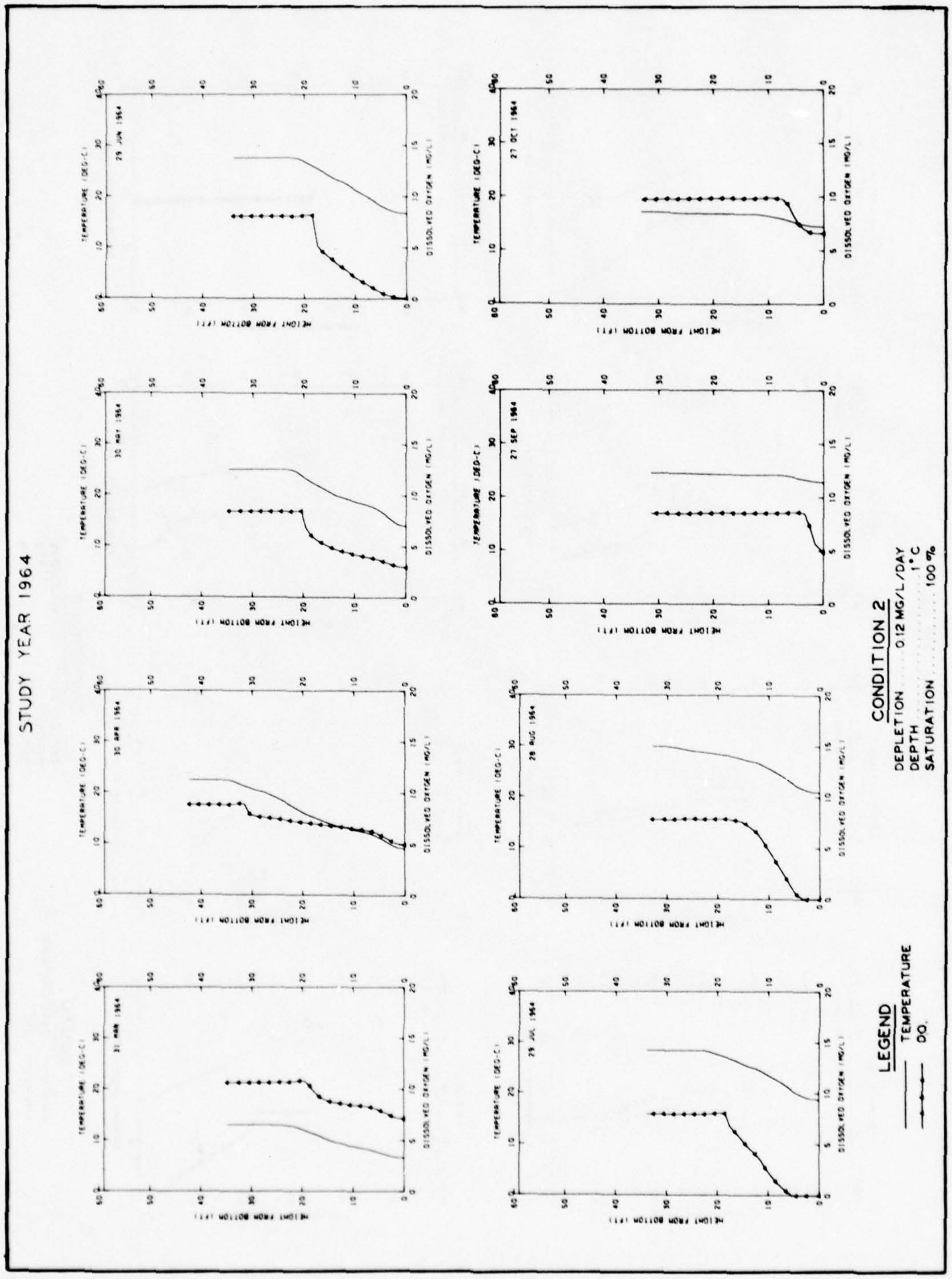
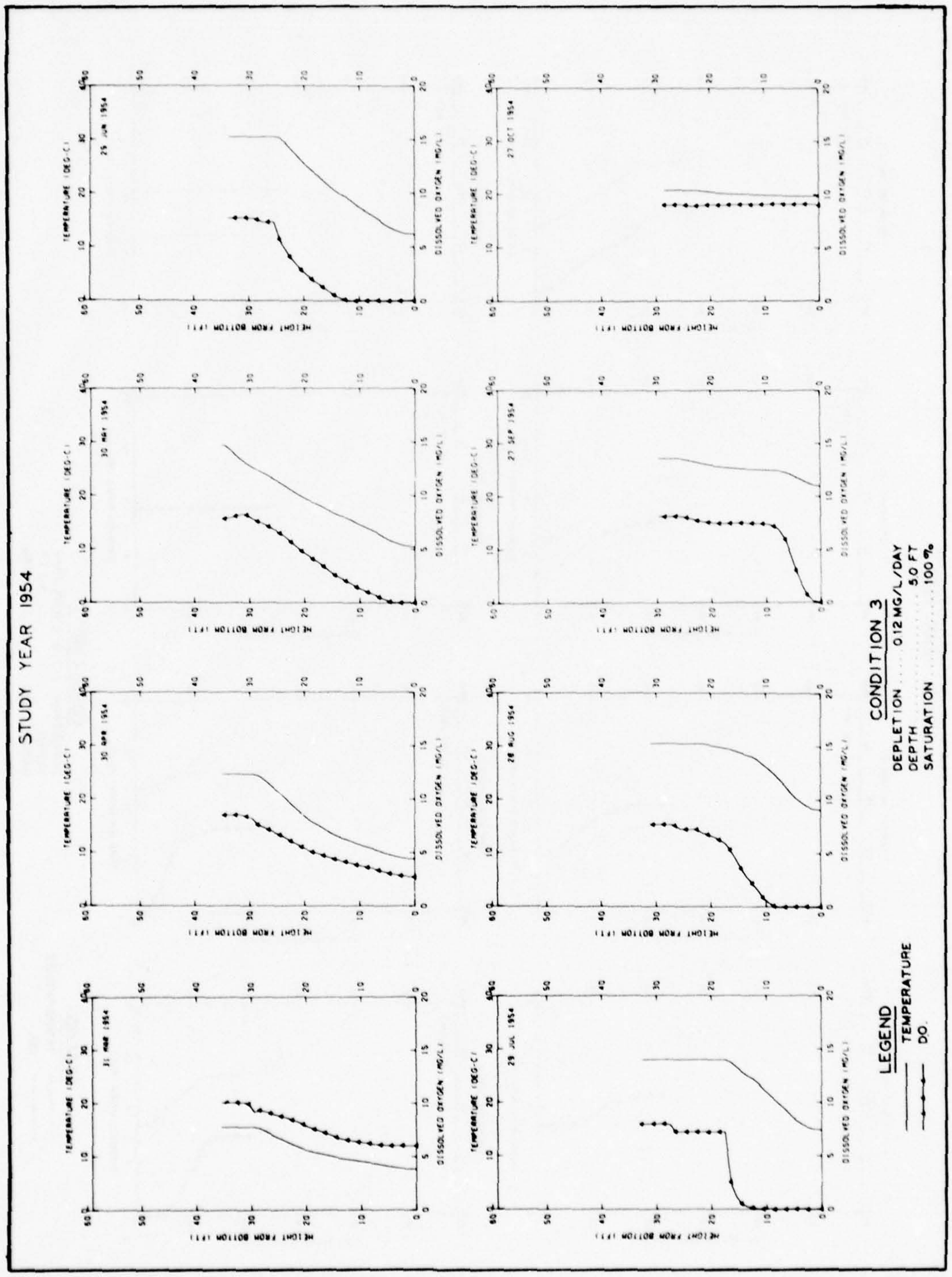


PLATE A3 (SHEET 10 OF 25)


STUDY YEAR 1954
31 MAR 1954
30 APR 1954
30 MAY 1954
29 JUN 1954
29 JUL 1954
28 AUG 1954
27 SEP 1954
27 OCT 1954
TEMPERATURE (DEG-C)
DISSOLVED OXYGEN (MG/L)
HEIGHT FROM BOTTOM (FT)
LEGEND
TEMPERATURE
D.O.
CONDITION 3
DEPLETION .... 0.12 MG/L/DAY
DEPTH .... 50 FT
SATURATION 100%

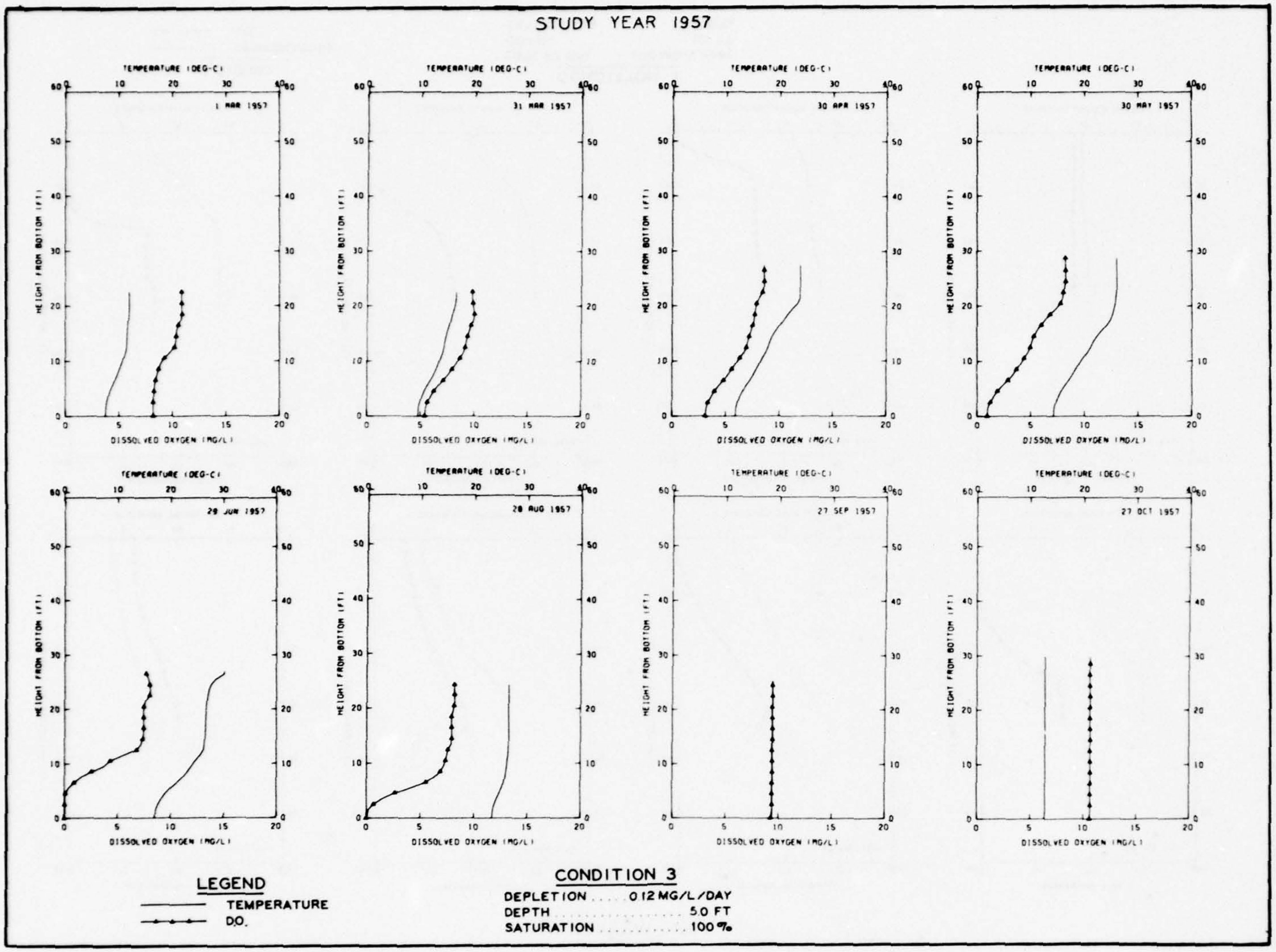


PLATE A3 (SHEET 12 OF 25)

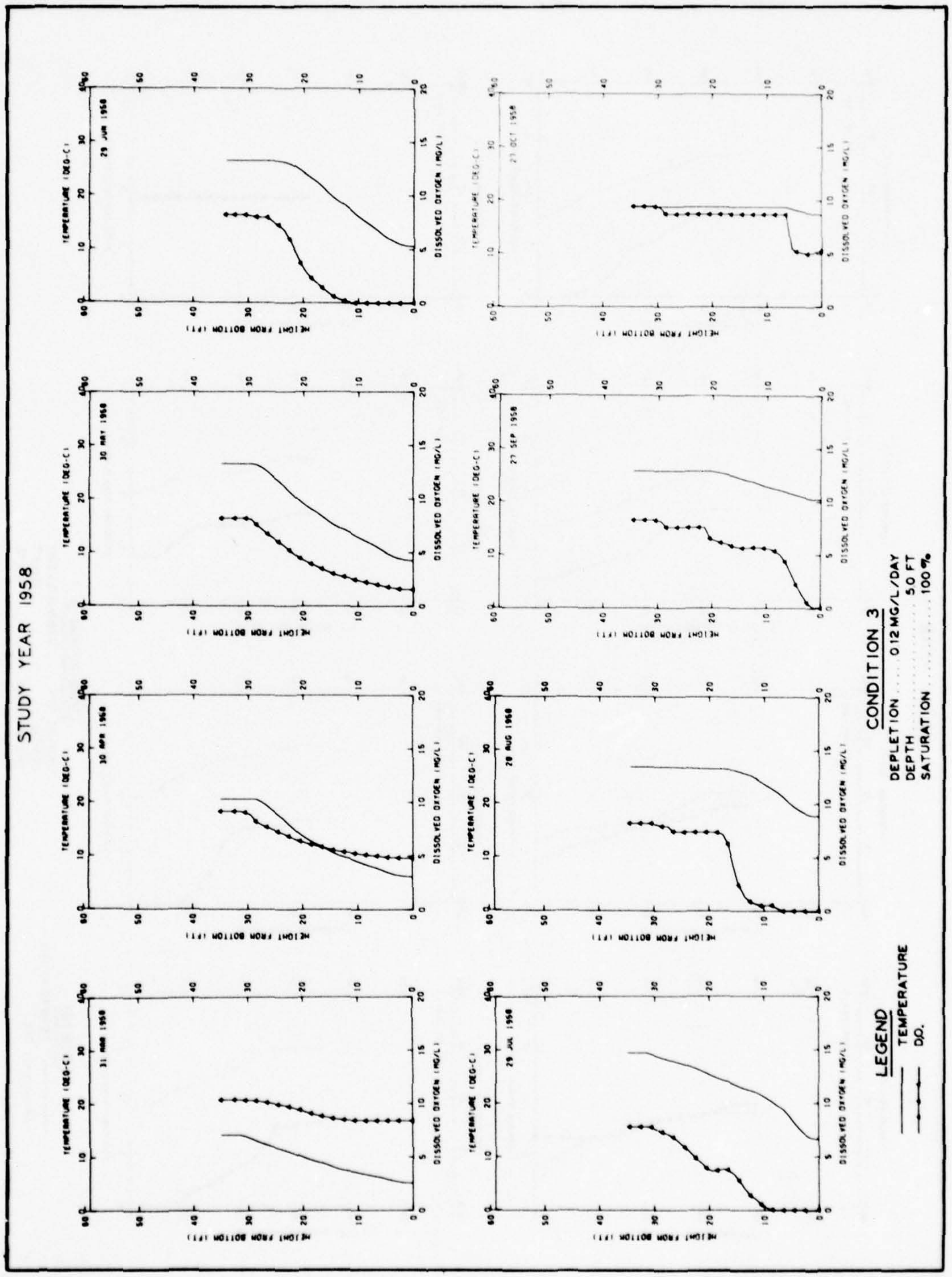


PLATE A3 (SHEET 13 OF 25)

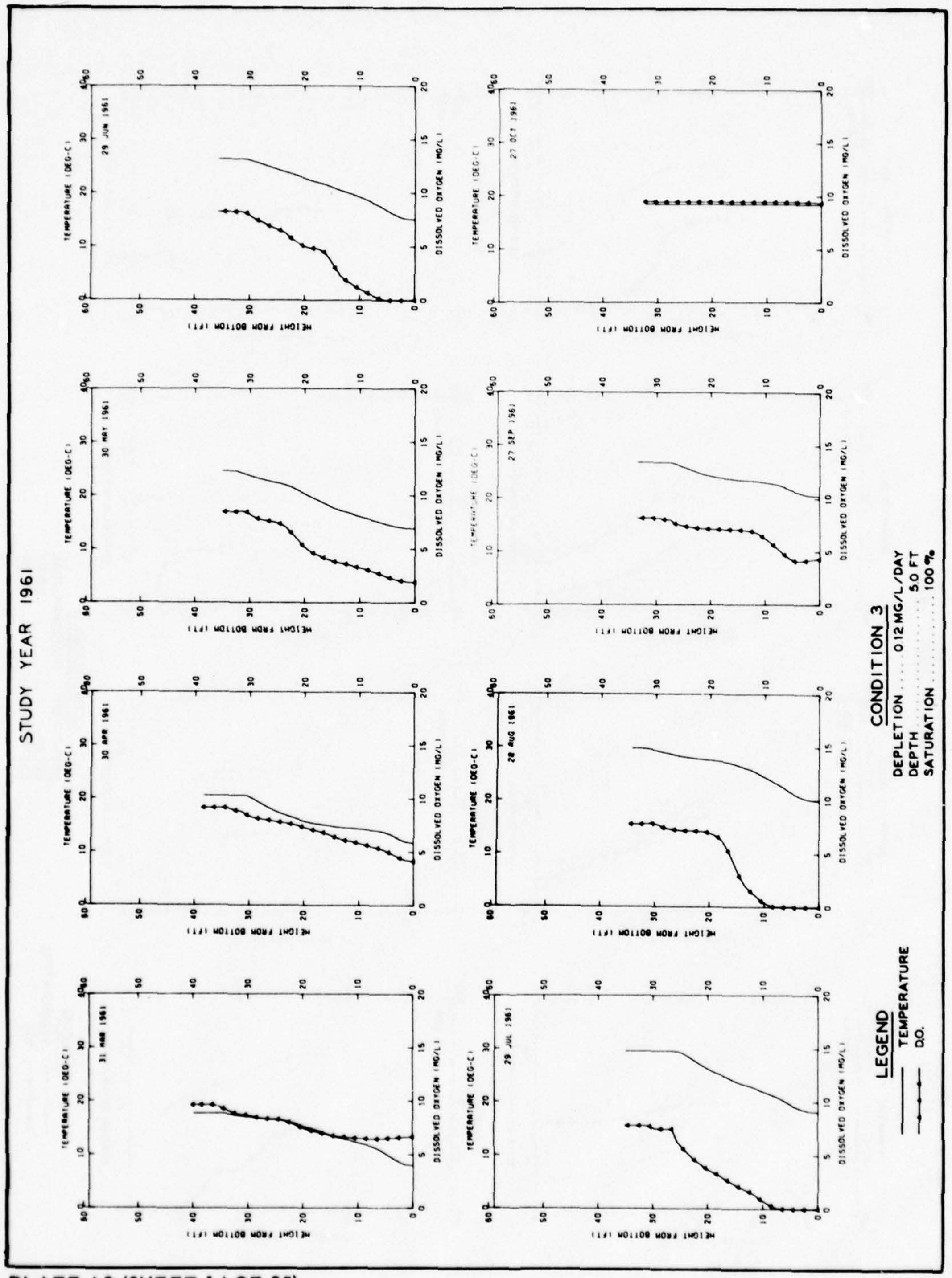


PLATE A3 (SHEET 14 OF 25)

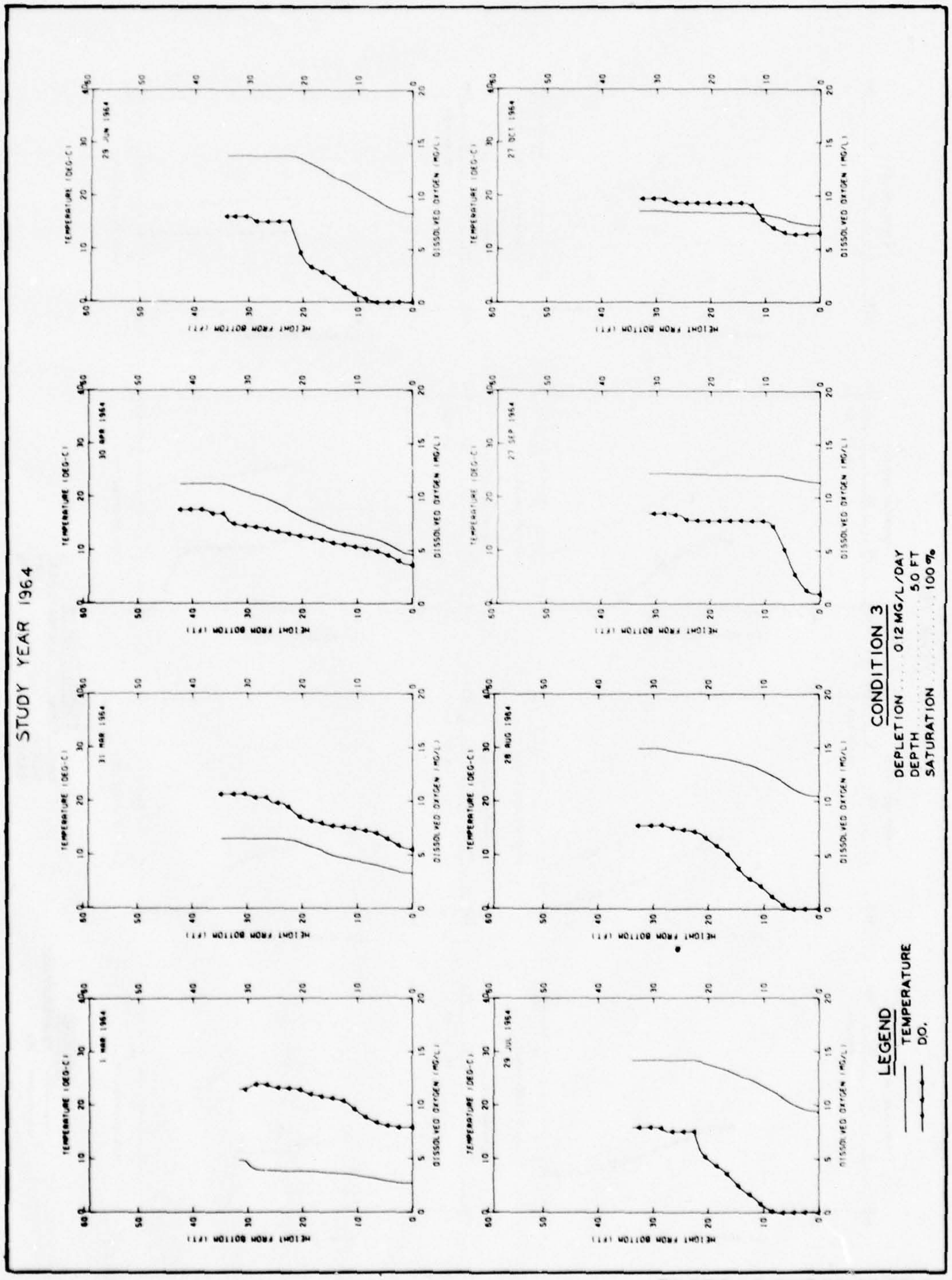


PLATE A3 (SHEET 15 OF 25)

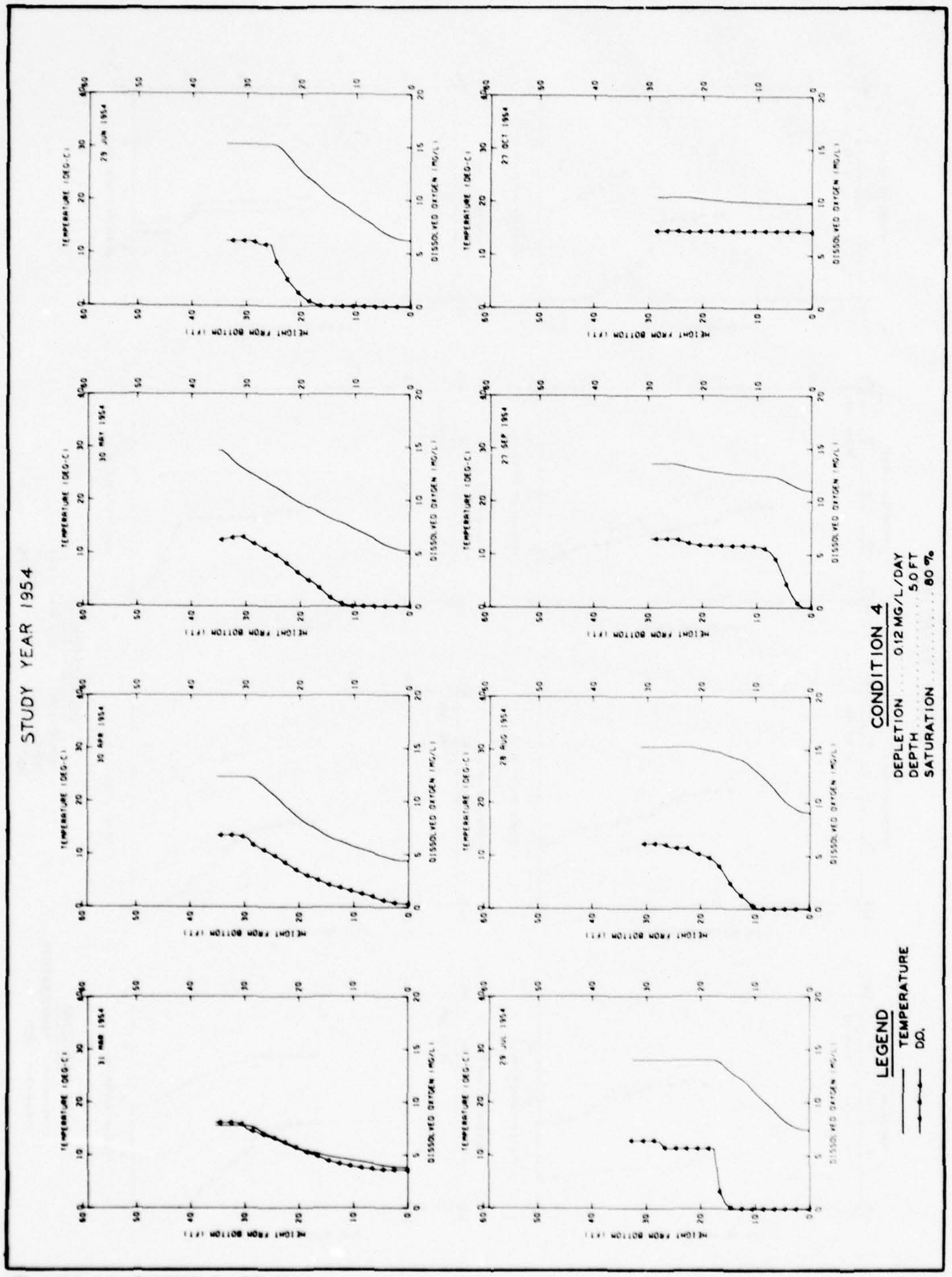
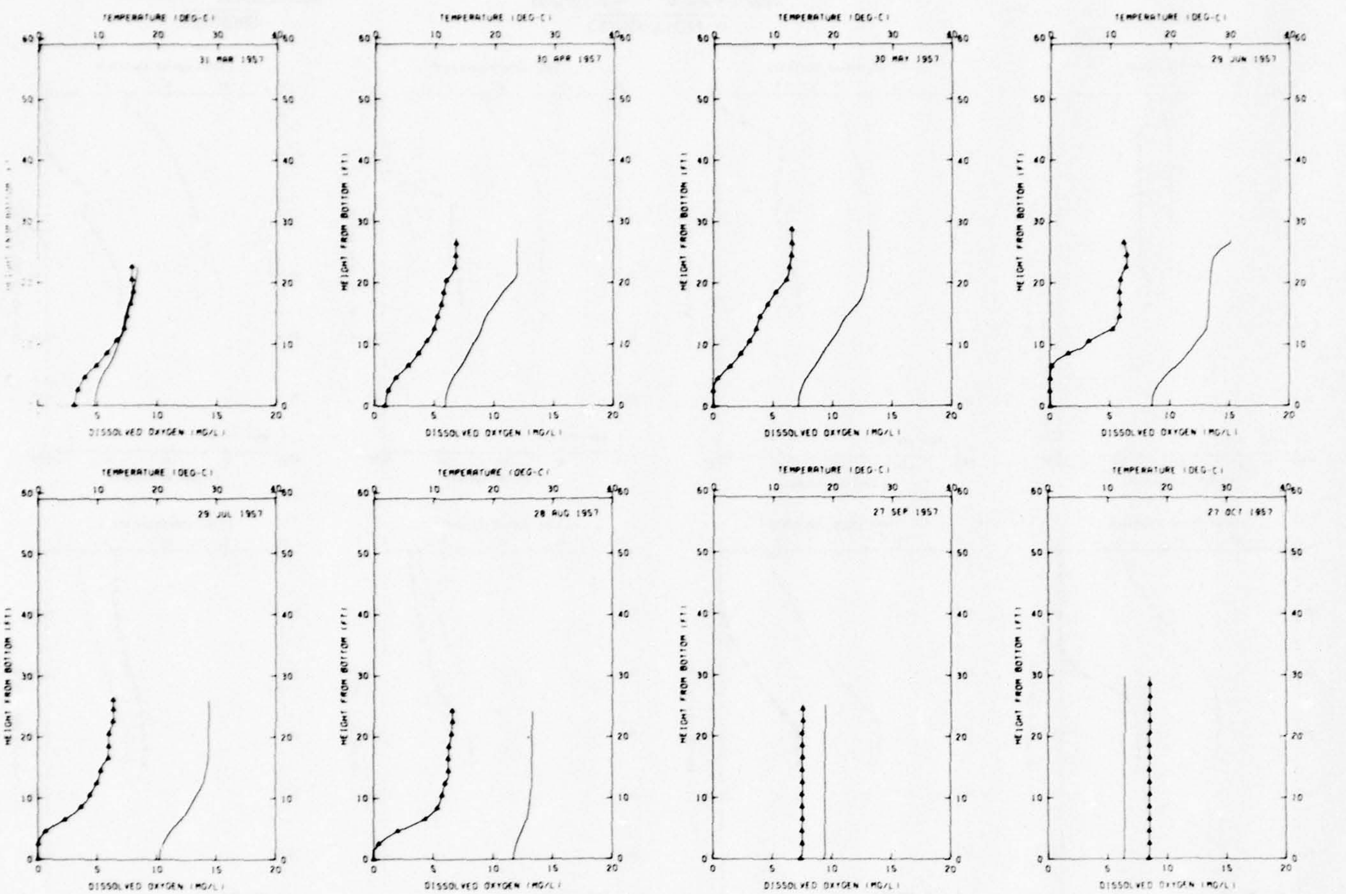


PLATE A3 (SHEET 16 OF 25)

STUDY YEAR 1957



LEGEND
TEMPERATURE
D.O.

CONDITION 4
DEPLETION ...... 0.12 MG/L/DAY
DEPTH .... 50 FT
SATURATION .... 80 %

PLATE A3 (SHEET 17 OF 25)

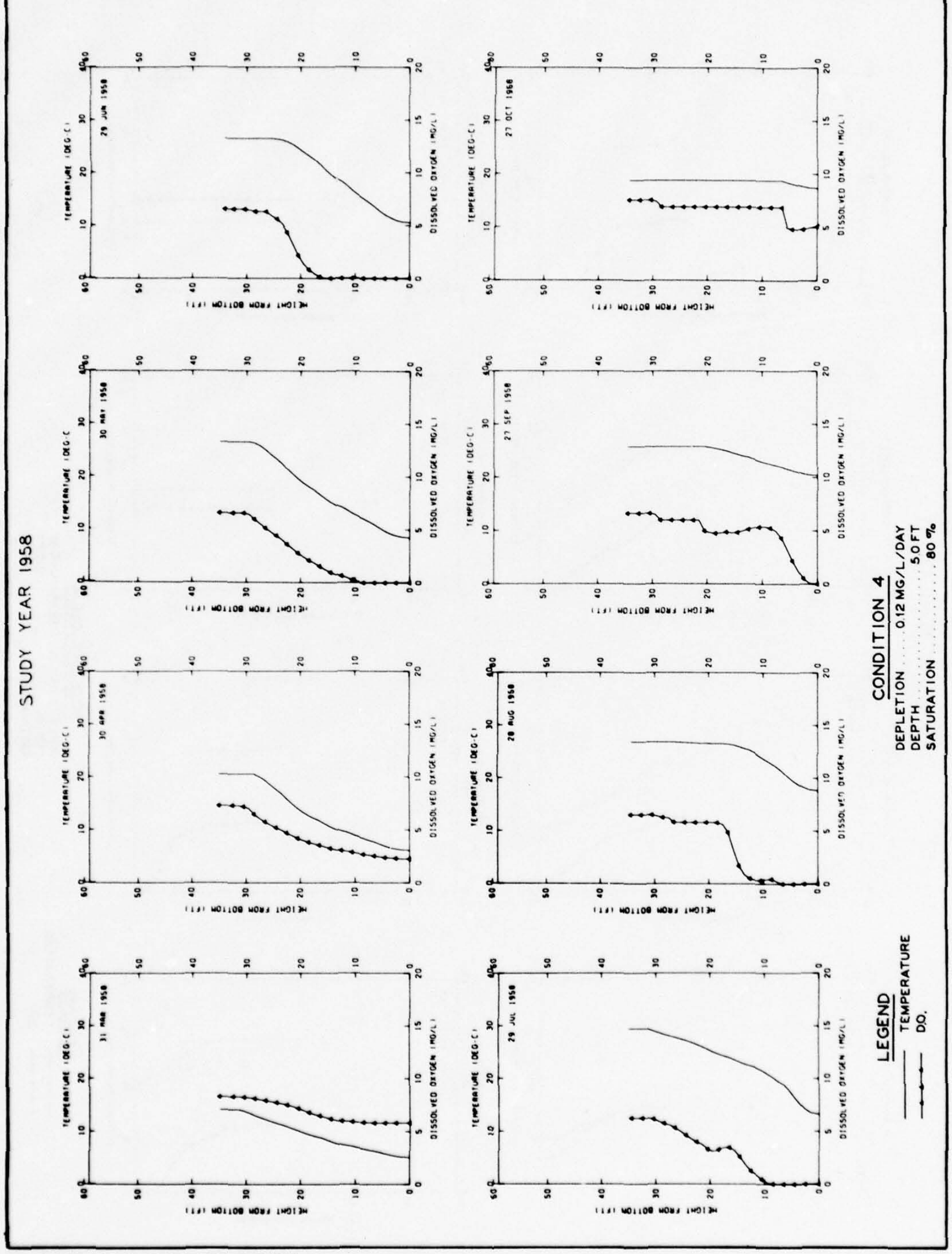
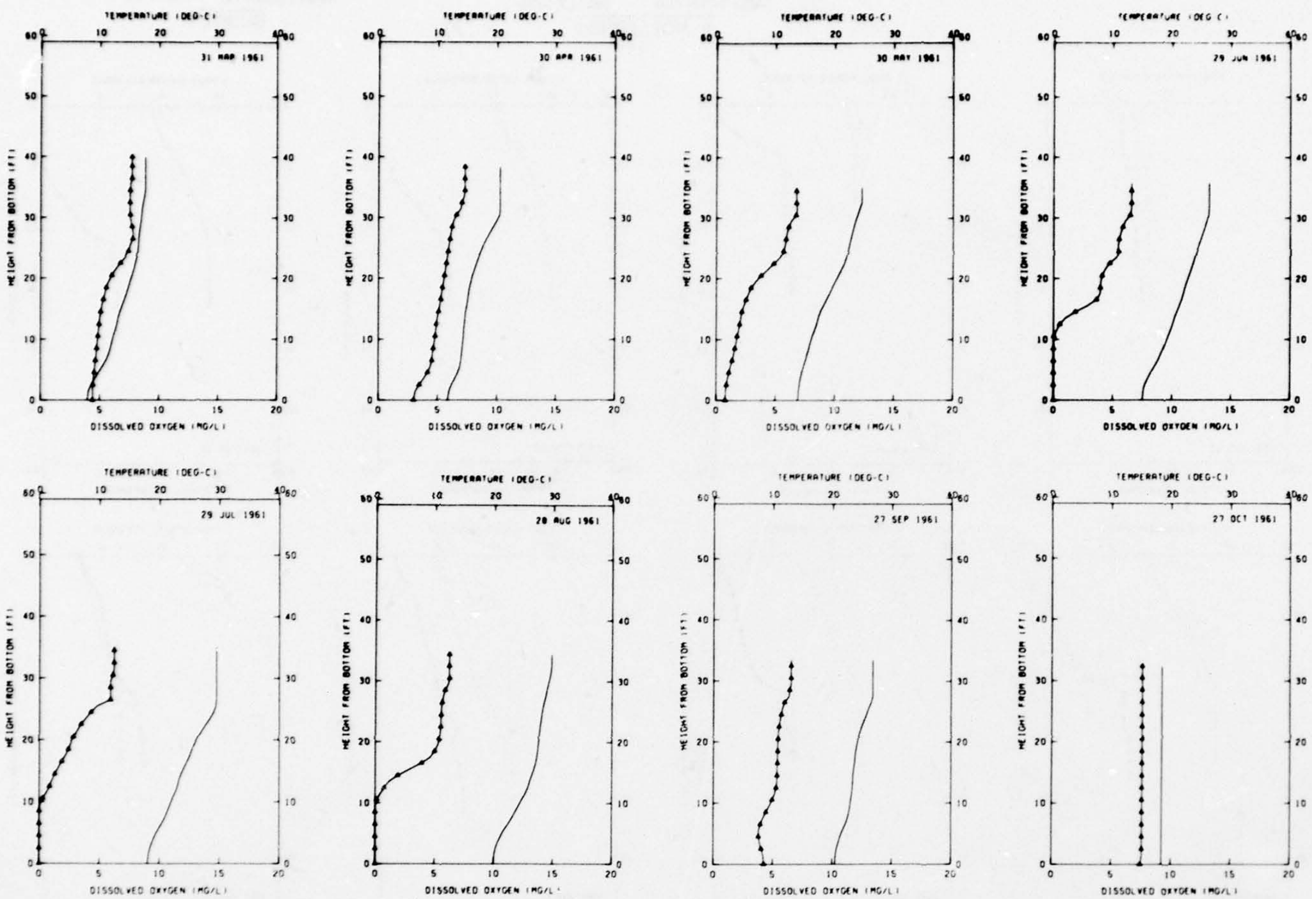


PLATE A3 (SHEET 18 OF 25)

STUDY YEAR 1961



LEGEND

TEMPERATURE

D.O.

CONDITION 4

DEPLETION ..... 0.12 MG/L/DAY

DEPTH .... 5.0 FT

SATURATION .... 80 %

PLATE A3 (SHEET 19 OF 25)

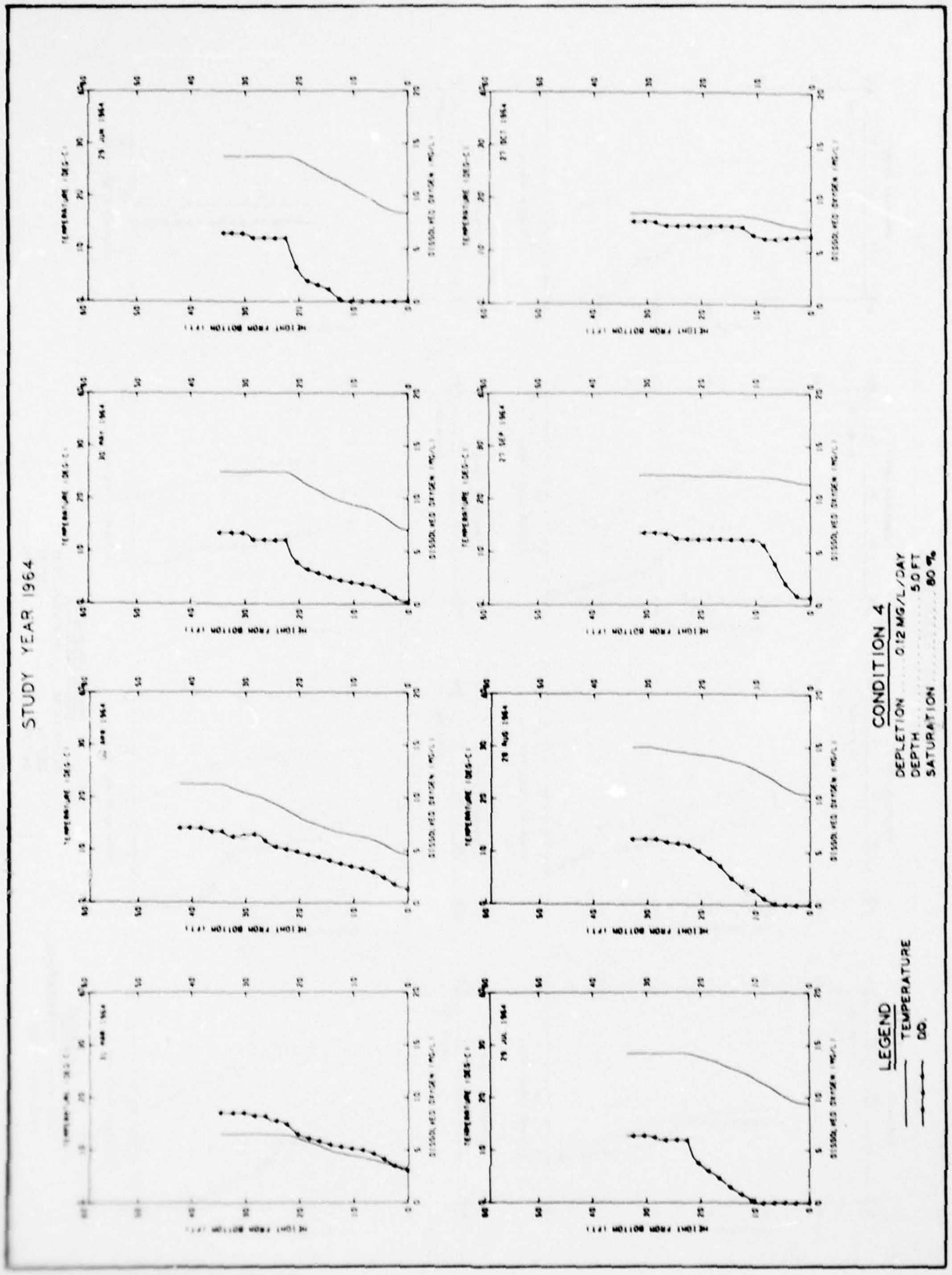
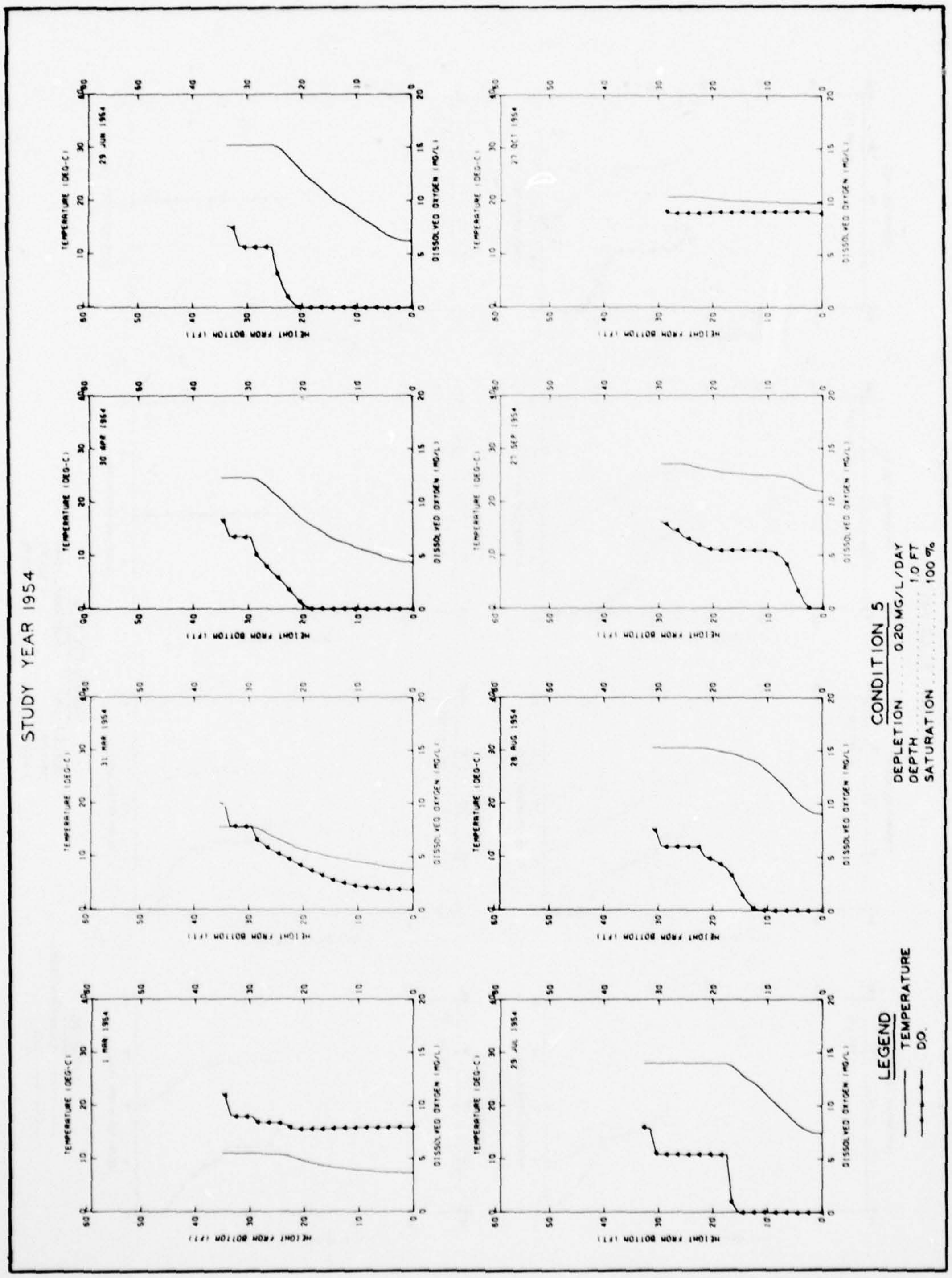


PLATE A3 (SHEET 20 OF 25)


STUDY YEAR 1954
1 MAR 1954
31 MAR 1954
30 APR 1954
29 JUN 1954
29 JUL 1954
28 AUG 1954
27 SEP 1954
27 OCT 1954
TEMPERATURE (DEG-C)
DISSOLVED OXYGEN (MG/L)
HEIGHT FROM BOTTOM (FT)
LEGEND
TEMPERATURE
D.O.
CONDITION 5
DEPLETION .... 0.20 MG/L/DAY
DEPTH .... 1.0 FT
SATURATION 100%

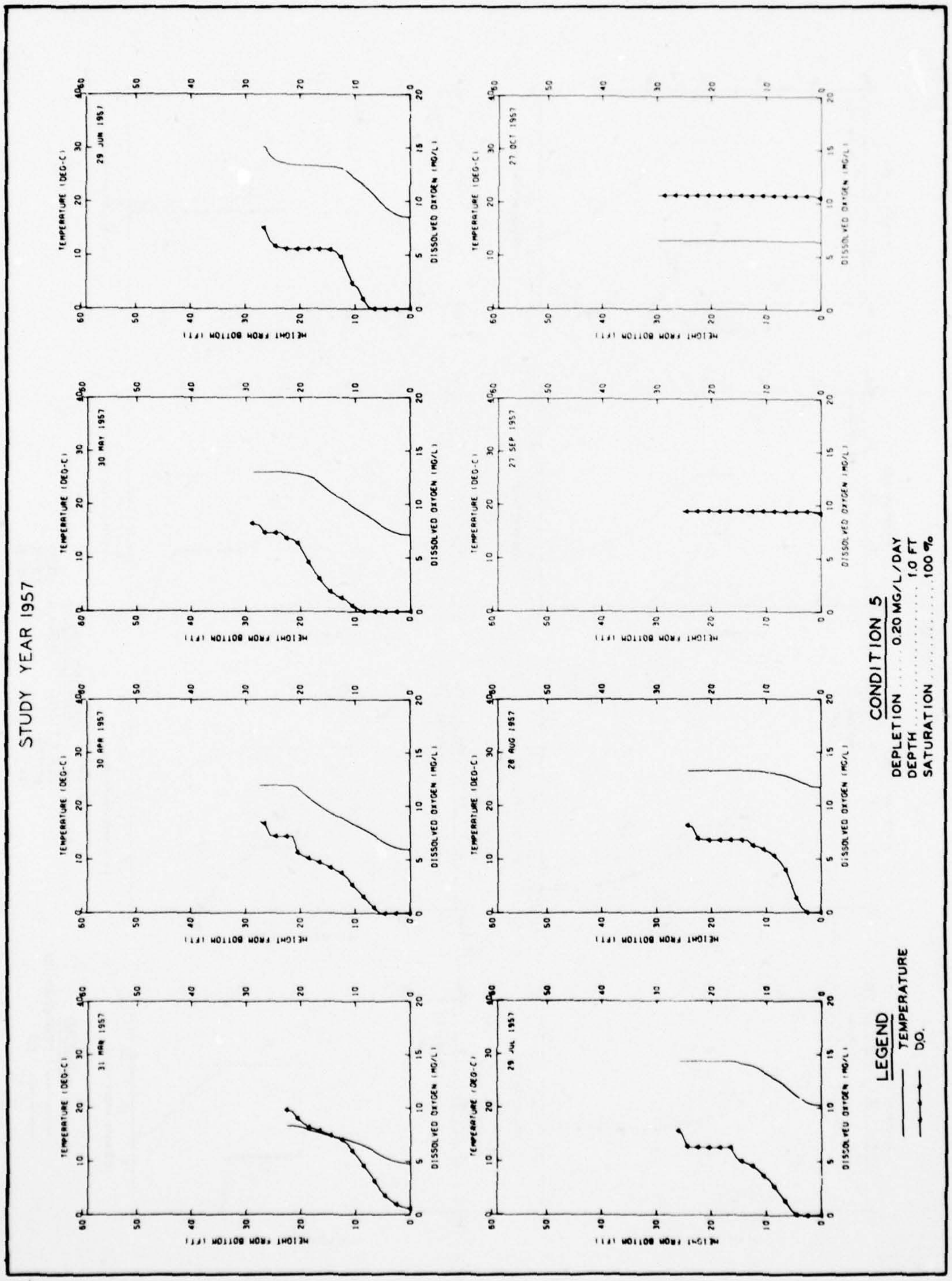


PLATE A3 (SHEET 22 OF 25)

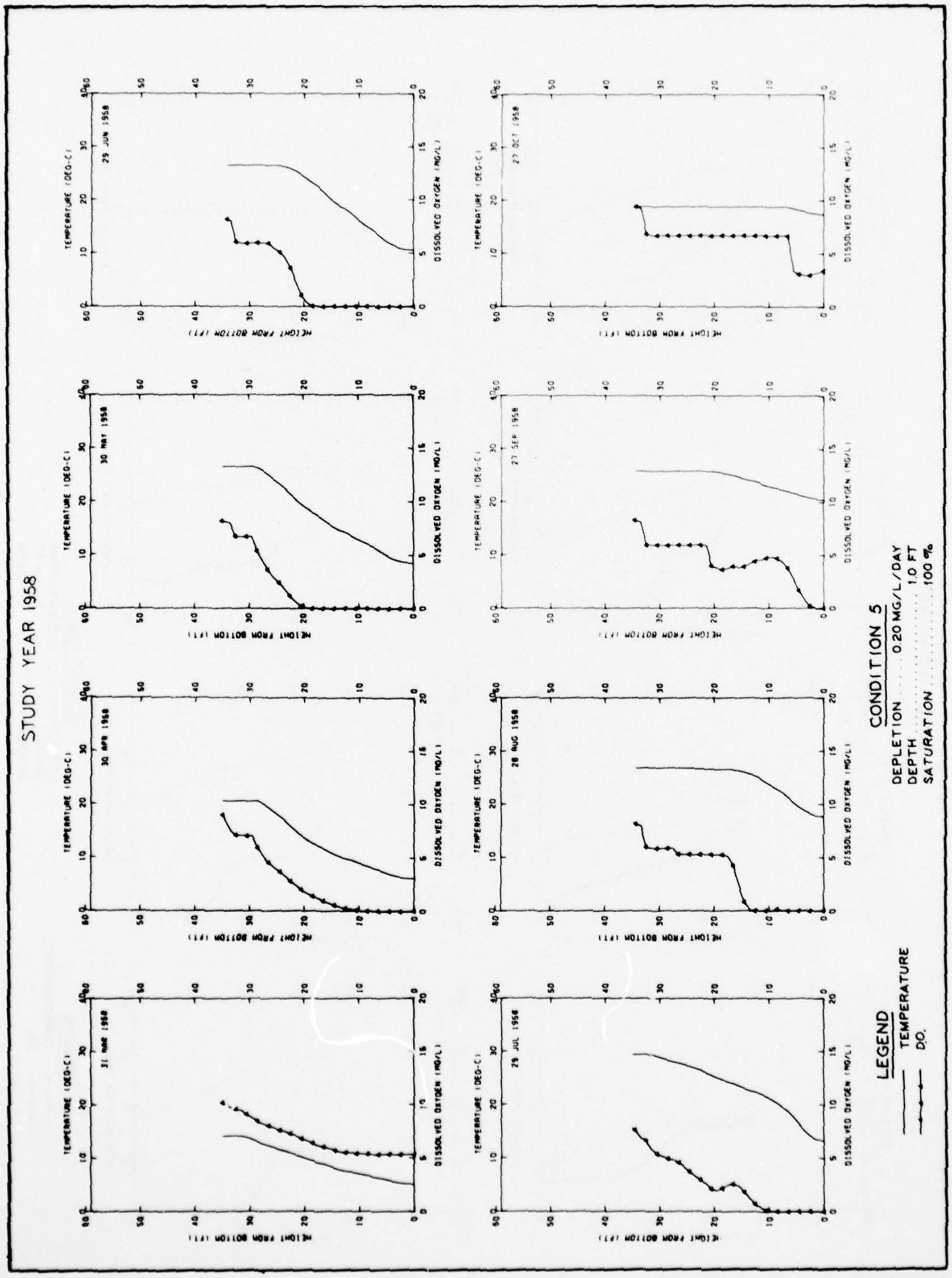


PLATE A3 (SHEET 23 OF 25)

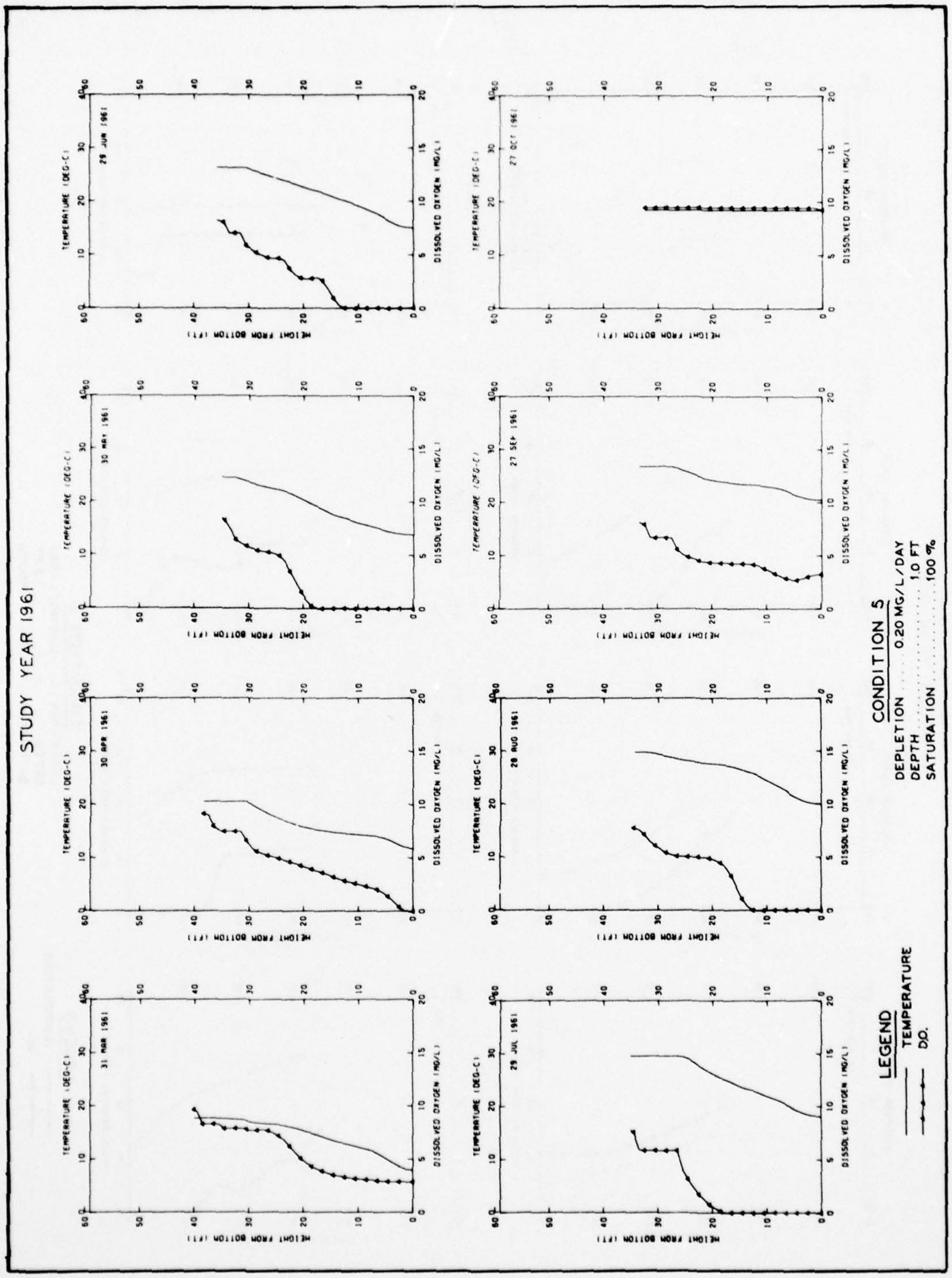
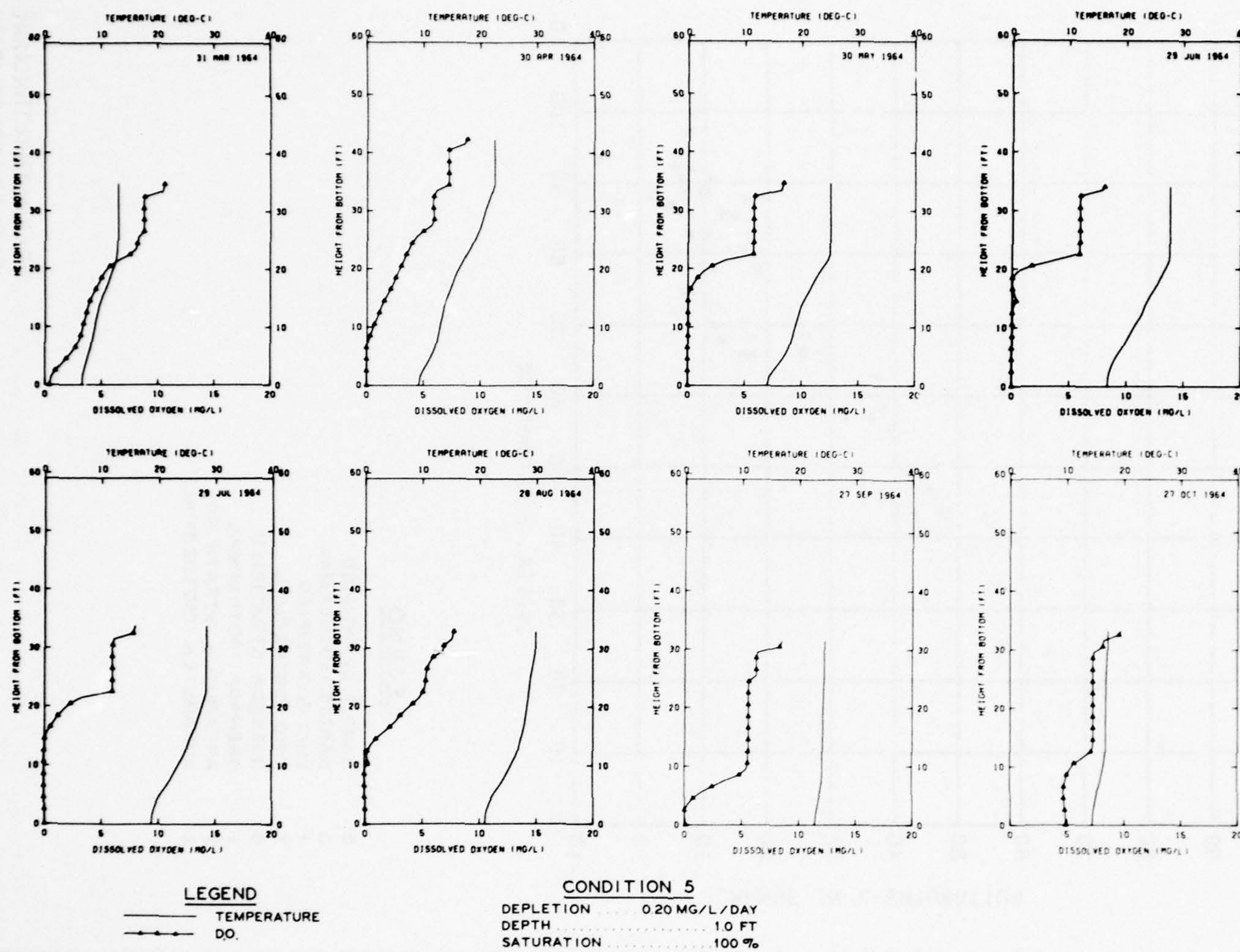


PLATE A3 (SHEET 24 OF 25)

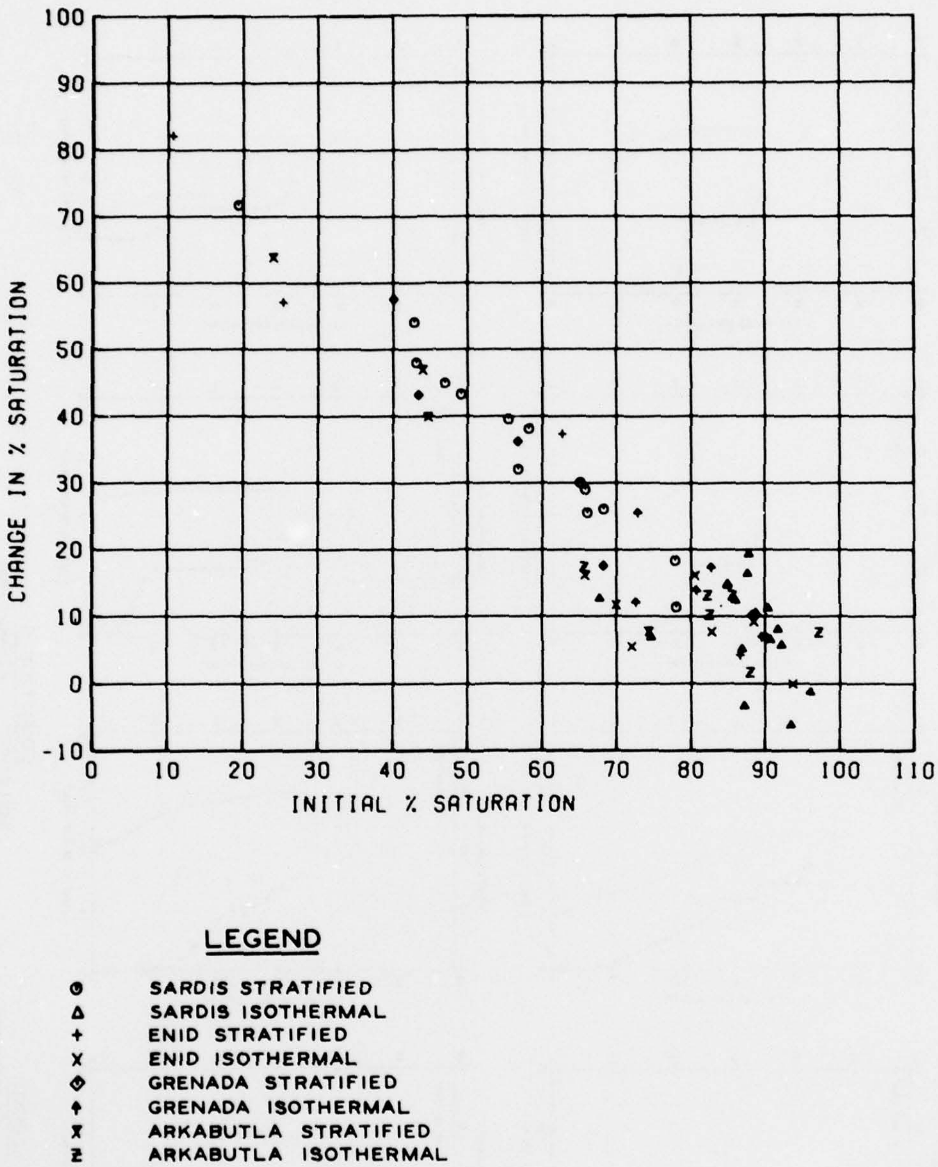
STUDY YEAR 1964



CONDITION 5

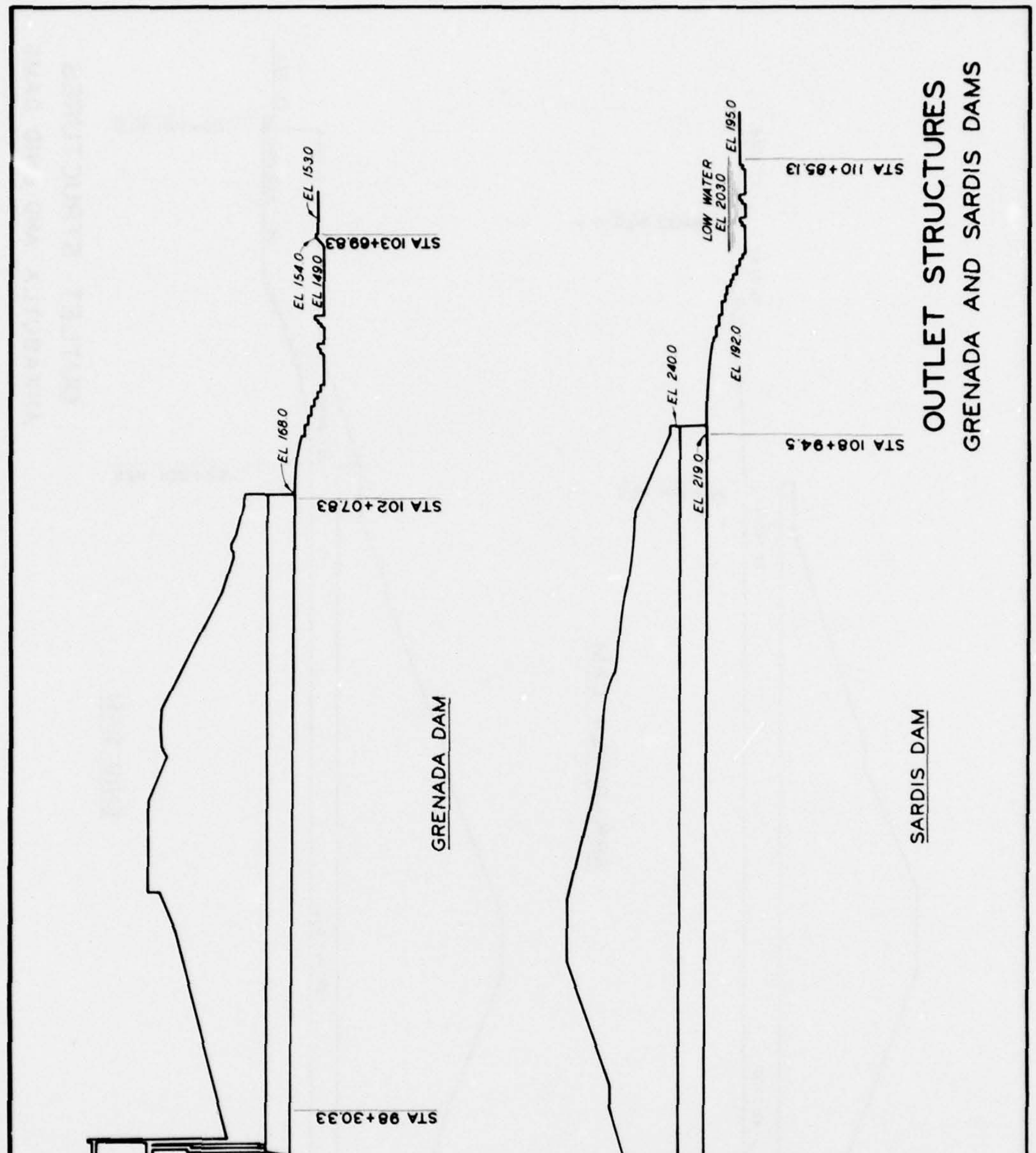
DEPLETION . . . . . 0.20 MG/L/DAY
DEPTH . . . . 1.0 FT
SATURATION . . . . 100 %

PLATE A3 (SHEET 25 OF 25)



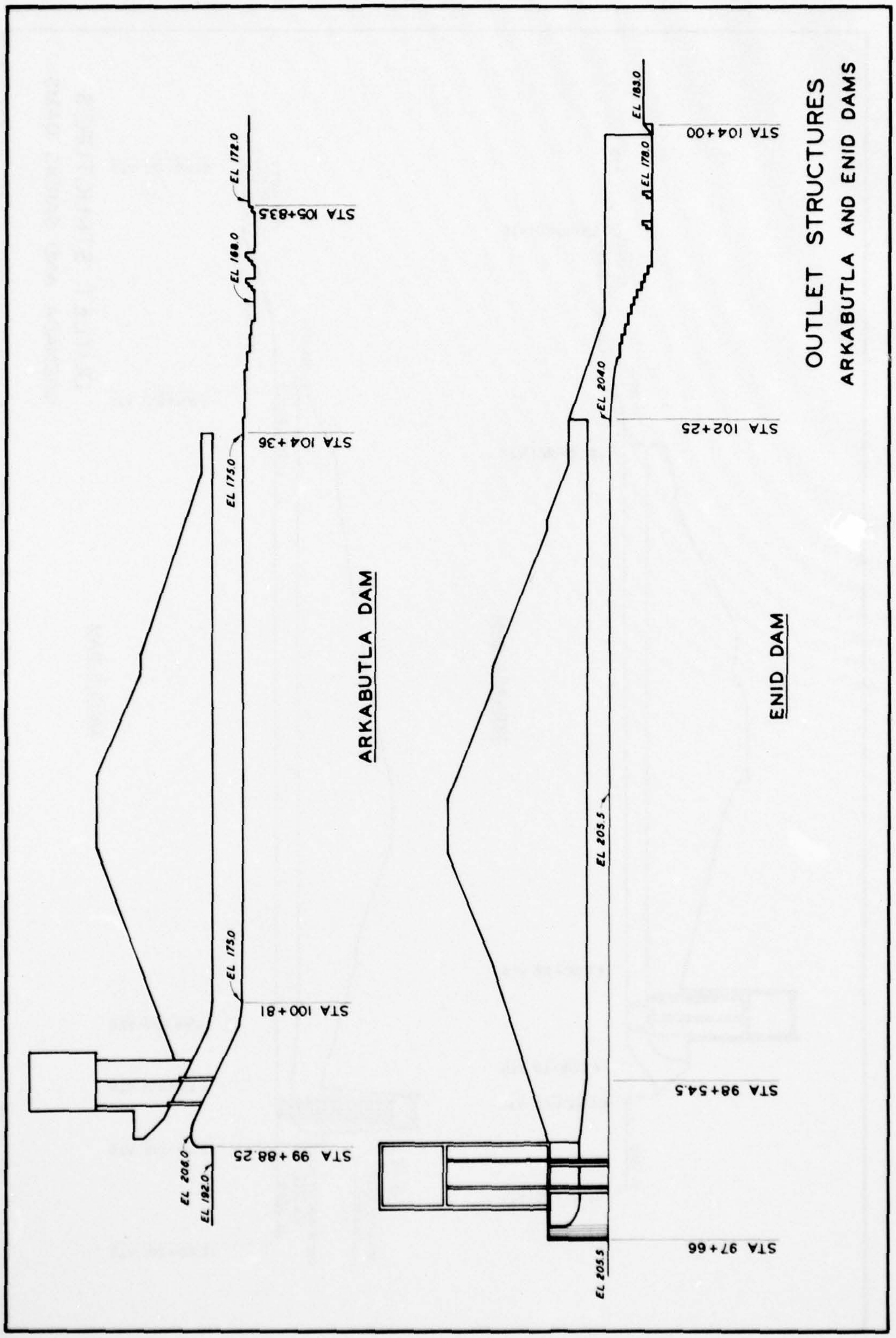
REAERATION THROUGH
OUTLET STRUCTURES
NORTHERN MISSISSIPPI

PLATE A4



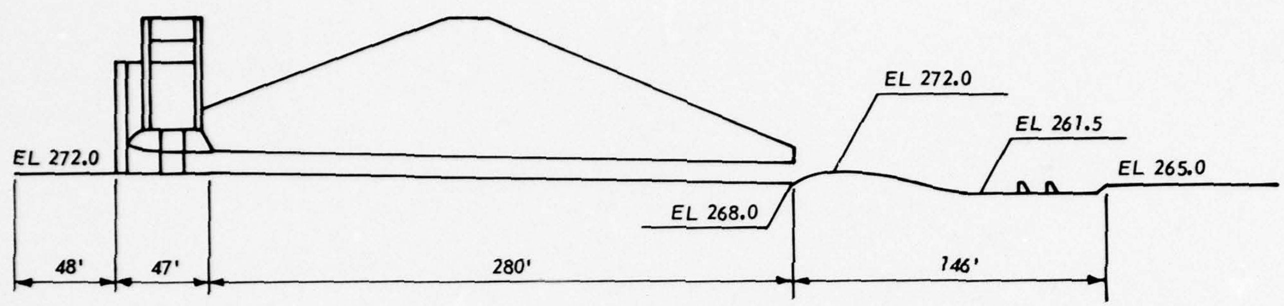
OUTLET STRUCTURES
GRENADA AND SARDIS DAMS

PLATE A5



OUTLET STRUCTURES
ARKABUTLA AND ENID DAMS

PLATE A6



OUTLET STRUCTURE
TALLAHAHA CREEK LAKE DAM

APPENDIX B: EFFECTS OF A SIMPLE OPERATION PLAN

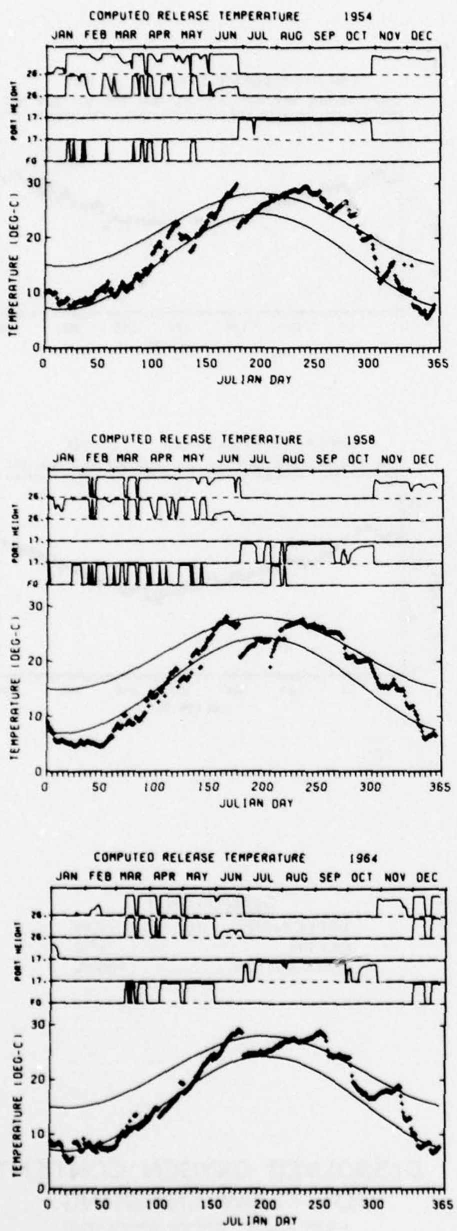
1. The original simulations of Tallahala Creek Lake were conducted by allowing the model to select the appropriate ports during every time step in order to best meet the specified downstream temperature objective. This daily optimal procedure is optimal in the sense that the release temperature for any day is as close as possible to the objective temperature for that day. However, a lake is a dynamic system, and a series of optimal releases does not provide the same results as a schedule of optimal releases based on an entire year of simulation. For example, the release of cold water to meet an objective temperature in the spring or summer might deplete the cold water required in the early fall. In addition to the problems involved in determining an operation schedule which will best meet downstream water-quality requirements, the actual operation of a lake according to a daily optimal schedule is not necessarily the most practical mode of operation. Daily optimal operation may require continual gate changes based on current and expected future temperature conditions. Considering the greater requirements of daily optimal operation, a simple operation schedule was simulated; and the results were compared with results of simulations in which daily optimal releases were used.

2. For these additional simulations, the intake configuration used was type II as discussed in the main text of this report. D.O. content was simulated using a constant oxygen depletion rate of 0.12 mg/ℓ/day and surface saturation of 100 percent down to the depth at which the temperature was 1°C less than the surface temperature. The operation plan investigated consisted of the following periods.

- a. 1 January-25 June: release of warmest water possible; all flow is from the highest selective-withdrawal ports if possible; excess is released through floodgate.
- b. 26 June-27 October: release of coldest water possible; flow is from the lowest selective-withdrawal ports except for flood flows which can be released from the floodgate. This period was included in an attempt to delay the buildup of water in the bottom with low D.O. content.

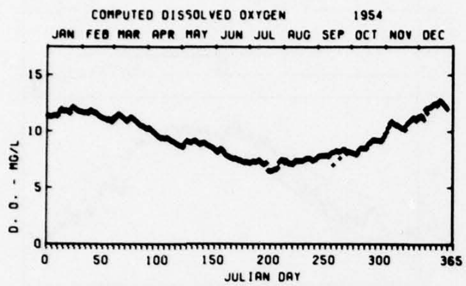
c. 28 October-31 December: release of warm water from highest selective-withdrawal ports. During this period, release flow will not include low D.O. water from the bottom except when flood releases are required.

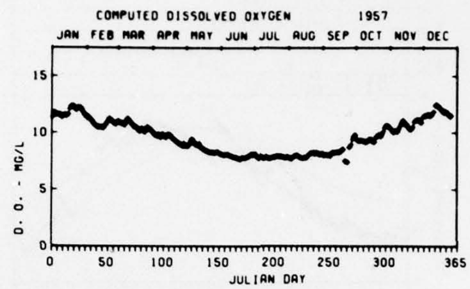
3. Computed release temperatures and D.O. concentrations are presented in Plates B1 and B2. Comparison of these results with Plate 7 in the main report and Plate A2 (sheet 2) in Appendix A indicate that release temperature and D.O. content are nearly the same for either the daily optimal procedure or the simple operation plan. The simple operation causes a large drop in release temperature and D.O. content as a result of the change from warm-water release to cold-water release. However, this transition could be accomplished gradually, thereby reducing the sharp 1-day temperature and D.O. gradients for the release.

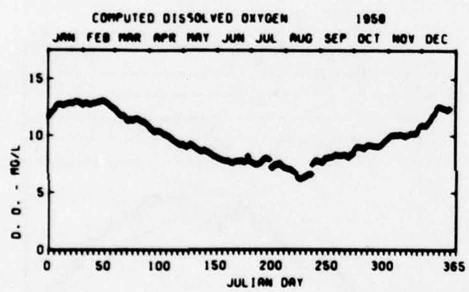


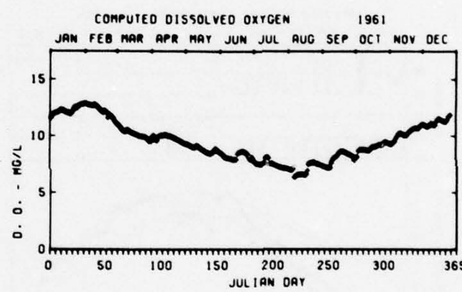
COMPUTED RELEASE TEMPERATURE

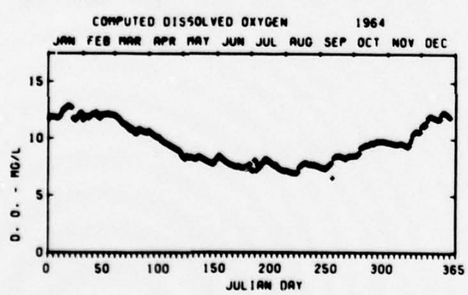
PLATE B1











<u>CONDITION 1</u>

DEPLETION.....0.05 MG/L/DAY
DEPTH....................1° C
SATURATION...........100%

DISSOLVED OXYGEN CONTENT
OF FLOW ENTERING
INTAKE STRUCTURE

AD-A052 620 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 8/8
TEMPERATURE ANALYSIS AND SELECTIVE-WITHDRAWAL DESIGN STUDY, TAL--ETC(U)
JAN 78 S T MAYNORD, B LOFTIS, D G FONTANE

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APPENDIX C: NOTATION

A,B,C,D	Coefficients of objective temperature curve
A	-13.834
B	1.721×10^{-2}
C	1.333
D	65.44
D.O.	Dissolved oxygen
$D.O._{inflow}$	Inflow D.O. content, mg/ℓ
$D.O._{sat}$	Temperature-dependent saturated D.O. content, mg/ℓ
e	Natural logarithmic base (2.7183)
E	Mean daily equilibrium temperature, °F
H	Net rate of surface heat transfer, Btu/ft^2/day
H_i	Rate of heat absorbed in layer (i), Btu/ft^2/day
H_s	Rate of heat transfer into or out of surface layer, Btu/ft^2/day
K	Coefficient of surface heat exchange, Btu/ft^2/day°F
Q	Mean daily streamflow, cfs
S	Rate of total incoming shortwave radiation, Btu/ft^2/day
t	Julian day
T	Stream temperature, °C
z_i	Depth below surface, ft
α,β	Regression coefficients
α	19.475
α_1	Mixing coefficient at surface
α_2	Mixing coefficient at bottom
β	Percentage of incoming shortwave radiation absorbed in the surface layer
β_1	-0.0020
β_2	0.13595
β_3	0.1234
β_4	0.4095
θ	Mean daily stream temperature, °F
λ	Absorption coefficient, ft^{-1}

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Maynord, Stephen T

Temperature analysis and selective-withdrawal design study, Tallahala Creek Lake, Mississippi; mathematical model investigation / by Stephen T. Maynord, Bruce Loftis, Darrell G. Fontane. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

23, [71] p., 61 leaves of plates : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; H-78-1)

Prepared for U. S. Army Engineer District, Mobile, Mobile, Alabama.

References: p. 22-23.

1. Dissolved oxygen. 2. Mathematical models. 3. Multilevel outlets. 4. Tallahala Creek Lake. 5. Thermal analysis. I. Loftis, Bruce, joint author. II. Fontane, Darrell G., joint author. III. United States. Army. Corps of Engineers. Mobile District. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; H-78-1.

TA7.W34 no.H-78-1